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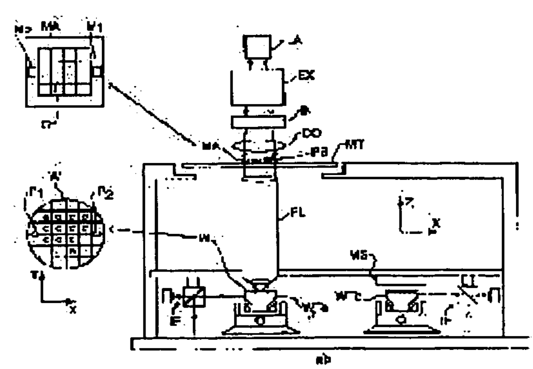
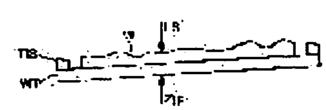
(54) OFF-AXIS LEVELING IN LITHOGRAPHIC PROJECTION APPARATUS

(57)Abstract:
PROBLEM TO BE SOLVED: To avoid for the necessity to relate origins of two interferometer systems by controlling position of a second substrate table in a first direction in accordance with a height map and a measured position, during exposure of a target portion of a substrate.
SOLUTION: A projection beam PB of radiation is supplied from a radiation system A to a mask MA, which is held with a first substrate table MT. An irradiated portion of a mask of a second substrate table WT is imaged on a target portion C of a substrate W by using a projection system PL. Position of the second substrate table WT in a first direction is controlled in accordance with a position measured with a height map and a position measuring means IF, during exposure of the target portion C of the substrate W. As a result, necessity to relate origins of two interferometer systems can be evaded.





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CLAIMS

[Claim(s)]
[Claim 1] the radiation system (LA --) for being lithography projection equipment and supplying the projection beam (PB) of :radiation The 1st body table equipped with the mask holder for holding Ex, IN, and CO; mask (MA) (MT); Have a substrate holder for holding a substrate (W). The 2nd movable body table (WT); projection system [for carrying out image formation of the irradiated part of this mask on the target part (C) of this substrate] (PL);, and the above-mentioned 2nd body table It has the physical reference side where the 2nd body table of; above was fixed to it in the projection equipment containing positioning system; for moving between the exposure station where the above-mentioned mask part is made in image formation by the above-mentioned projection system on the above-mentioned substrate, and a measurement station. Further projection equipment Two or more points on the front face of the substrate (W) which was located in the above-mentioned measurement station and held on the above-mentioned substrate holder, The height map creation means about the above-mentioned physical reference side constituted and arranged so that height might be measured and the height map might be made; It is located in the above-mentioned exposure station. In a list, The location measurement means for measuring the location in the 1st vertical direction substantially on the above-mentioned substrate front face of the above-mentioned physical reference side, after moving the above-mentioned 2nd body table to the above-mentioned exposure station; during exposure of the above-mentioned target part Equipment characterized by having control means; constituted and arranged so that the location of the above-mentioned 2nd body table in the 1st direction of the above might be controlled at least according to the above-mentioned location measured with the above-mentioned height map and the above-mentioned location measurement means.
[Claim 2] Equipment with which the above-mentioned control means is further established in the equipment by claim 1 so that the surrounding inclination of one shaft of the above-mentioned 2nd body table vertical to the 1st direction of the above at least may be controlled according to the above-mentioned height map.
[Claim 3] Equipment containing the level sensor constituted and arranged in the equipment by claim 1 or claim 2 so that the above-mentioned height map creation means might measure the location in the 1st direction of the above of the linearity array of a point.
[Claim 4] Equipment containing the level sensor (10) constituted and arranged so that the location of the measurement beam reflected in the equipment by claim 1, claim 2, or claim 3 by the front face where the above-mentioned height map creation means should measure the location in the 1st direction of the above might be measured.
[Claim 5] In the equipment by claim 4 the above-mentioned level sensor (10) the image of the :projection grid (113); above-mentioned projection grid The projection optical system for projecting on the front face which should measure the location in the 1st direction of the above (114); A detection grid (126), Equipment containing the detector (128) for detecting the moire graphic form which was able to do light reflected by the above-mentioned front face in order to make the image of the above-mentioned projection grid on the above-mentioned detection grid when the above-mentioned image of detection optical-system [for converging] (121); and the above-mentioned projection grid lapped with the above-mentioned detection grid.
[Claim 6] Equipment with which the above-mentioned projection optical system and the above-mentioned detection optical system change from a reflexibility optical element to a list intrinsically including the radiation source (111) in which the above-mentioned level sensor was constituted and arranged in the equipment by claim 5 so that the above-mentioned projection grid might be further illuminated with a multicolor radiation.
[Claim 7] The equipment with which the above-mentioned height map creation means includes the location

detection means (IF) for detecting the location in the 1st direction of the above of the above-mentioned 2nd body table in any of claim 1 thru/or claim 6, or the equipment by one in the measurement and the coincidence by the level sensor (10) for detecting the location in the 1st direction of the above of the front face of the above-mentioned substrate in respect of [describing above] plurality, and the above-mentioned level sensor.
[Claim 8] Equipment with which the above-mentioned location detection means contains an interferometer in the equipment by claim 7.
[Claim 9] Equipment with which the above-mentioned physical reference side includes the top face of the above-mentioned image sensors in any of claim 1 thru/or claim 8, or the equipment by one including the image sensors with which the above-mentioned location measurement means was attached in the above-mentioned 2nd body table.
[Claim 10] Equipment constituted and arranged in any of claim 1 thru/or claim 9, or the equipment by one so that the above-mentioned location measurement means might measure the location about the focal plane of the above-mentioned projection system of the above-mentioned physical reference side.
[Claim 11] Equipment constituted and arranged so that the above-mentioned 2nd body table might have two or more estranged physical reference sides and the above-mentioned height map creation means might measure the height about the reference flat surface formed of two or more above-mentioned physical reference sides of two or more points describing above in any of claim 1 thru/or claim 10, or the equipment by one.
[Claim 12] Are any of claim 1 thru/or claim 11, or equipment by one, and it is further located in the :above-mentioned exposure station. Are related with the above-mentioned physical reference side of two or more points on the front face of the substrate held on the above-mentioned substrate holder describing above. In order to draw the relative calibration for the separate location detection system formed in 2nd height map creation means;, the above-mentioned measurement, and the exposure station which were constituted and arranged so that height may be measured and the height map may be made Equipment containing calibration means; constituted and arranged so that the height map of the single substrate prepared by each of the above-mentioned 1st and 2nd height map creation means might be compared.
[Claim 13] the radiation system (LA --) for being the approach of manufacturing a device using the lithography projection equipment which has the following configurations, and supplying the projection beam (PB) of :radiation The 1st body table equipped with the mask holder for holding Ex, IN, and CO; mask (MA) (MT); Have a substrate holder for holding a substrate (W). The projection system for carrying out image formation of 2nd movable body table (WT); and the irradiated part of this mask on the target part (C) of this substrate (PL), On the above-mentioned 1st body table, a pattern In the approach containing process; which carries out image formation of process; which forms the substrate (W) which has a radiation induction layer on the above-mentioned 2nd body table, and the above-mentioned irradiated part of this mask on the above-mentioned target part of this substrate The process which prepares the mask (MA) which ****; in front of the :above-mentioned image formation process On this 2nd body table at a measurement station, two or more points on this substrate front face, The process which makes the height map about the physical reference side on the above-mentioned 2nd body table in which height is shown; This 2nd body table is moved to the above-mentioned exposure station. In a list, The process which measures the location in the 1st vertical direction substantially on the above-mentioned substrate front face of the above-mentioned physical reference side; in the above-mentioned image formation process The approach characterized by having process; which positions this 2nd body table in the 1st direction of the above at least with reference to the above-mentioned location measured in the 1st direction of the above of the above-mentioned height map and the above-mentioned physical reference side.
[Claim 14] How to orient the above-mentioned 2nd body table with the surroundings of one shaft vertical to the 1st direction of the above at least in the approach by claim 13 by referring to the above-mentioned height map in the above-mentioned image formation process.
[Claim 15] The approach this focal gap is distance [in / it arranges and / the 1st direction of / between the focal plane of the above-mentioned projection lens, and the front face of the above-mentioned substrate] as square of the focal gap which continued and integrated with the above-mentioned 2nd body table to the field of the above-mentioned target part in the above-mentioned image formation process in the approach by claim 13 or claim 14 is made into min.
[Claim 16] The approach arrange so that the square of the focal gap which continued and integrated with the above-mentioned 2nd body table to the field of the above-mentioned target part in the above-mentioned image-formation process in the approach by claim 13 or claim 14, including the process to which the above-

mentioned image-formation process carries out the scan image formation of the slit image on the above-mentioned substrate may make into min, and this focal gap means the distance in the 1st direction of the above of [between the focal plane of the above-mentioned projection lens, and the front face of the above-mentioned substrate].

[Claim 17] The process which measures the location in each 1st direction of the above of two or more points on the approach:above-mentioned substrate front face where the process which makes the above-mentioned height map includes the following sub processes in any of claim 13 thru/or claim 16, or the approach by one describing above; to each measurement and coincidence of the location of the point on the above-mentioned substrate front face The process which lengthens each of the measuring point of process; which measures the location in the 1st direction of the above of the above-mentioned 2nd body table, and the above-mentioned 2nd body table from the measuring point to which the above-mentioned substrate front face for making the above-mentioned height map corresponds.

[Claim 18] The approach the process which makes the above-mentioned height map includes simultaneously the initial process which measures the location in the 1st direction of the above of the above-mentioned physical reference side, and the location in the 1st direction of the above of the above-mentioned 2nd body table in the approach by claim 17.

[Claim 19] They are any of claim 13 thru/or claim 18, or an approach by one. Further Before the process which makes the above-mentioned height map : The process which measures the height of two or more points on the above-mentioned wafer front face which approaches around the field on the above-mentioned substrate which should be exposed, An approach including the process which determines the local height or dip value of a field with the above-mentioned substrate front face which should use the height for [whole] the above-mentioned substrate and dip, and/or its height as a map from the height measured in the list.

[Claim 20] They are any of claim 13 thru/or claim 19, or an approach by one. Further The level sensor (10) which should be used before the process which makes the above-mentioned height map in case the above-mentioned height map is made An approach including the process proofread by arranging two or more measurement of the vertical position of at least one predetermined point on the above-mentioned substrate front face to a different vertical position to that from which two or more above-mentioned measurement of this 2nd body table differs, and performing it using the above-mentioned level sensor.

[Claim 21] How to apply, in case the height map of the exposed region corresponding to that to which the above-mentioned calibration process was performed in the approach by claim 20 to the exposed region where the plurality on the above-mentioned substrate differs, and the type performed this calibration for the calibration correction value acquired to each is made.

[Claim 22] The device manufactured by any one approach of claim 13 thru/or claim 21.

[Claim 23] the radiation system (LA --) for being the approach of proofreading the lithography projection equipment which has the following configurations, and supplying the projection beam (PB) of :radiation The 1st body table equipped with the mask holder for holding Ex, IN, and CO; mask (MA) (MT); Have a substrate holder for holding a substrate (W). The 2nd, A movable body table (WT); The projection system for carrying out image formation of measurement station; which has the 1st location detection system (20a) for measuring the location in this station of the above-mentioned 2nd body table in a list, and the irradiated part of this mask on the target part (C) of this substrate (PL) and exposure station; which has the 2nd location detection system (20b) for measuring the location in this station of the above-mentioned 2nd body table -- at the process; above-mentioned measurement station which forms a substrate (W) in the above-mentioned 2nd body table The process which makes the 1st height map of the above-mentioned substrate substantially the location in the 1st vertical direction, and by measuring the location of the above-mentioned 2nd body table using the above-mentioned 1st location detection system simultaneously on the front face of the above-mentioned substrate of two or more points on the above-mentioned substrate front face; at the above-mentioned exposure station The location in the 1st direction of the above of two or more points on the above-mentioned substrate front face describing above, and by measuring the location of the above-mentioned 2nd body table using the above-mentioned 2nd location detection system simultaneously The process which makes the 2nd height map of the above-mentioned substrate; how to contain process; [/ map / above-mentioned / 1st and 2nd height], in order to proofread the above-mentioned 1st and 2nd location detection system in a list.

[Claim 24] The 1st body table which is the approach of manufacturing a device using the lithography projection equipment which has the following configurations, and is equipped with the mask holder for holding :mask (MA) (MT); Have a substrate holder for holding a substrate (W). The 2nd, Movable body table (WT); and the irradiated part of this mask The process which prepares the mask (MA) which **** a

pattern on the 1st body table of the projection (system PL); above for carrying out image formation on the target part (C) of this substrate; process; which forms the substrate (W) which has a radiation induction layer on the above-mentioned 2nd body table, and the above-mentioned irradiated part of this mask In order to expose two or more substrates including process; which carries out image formation on the above-mentioned target part of this substrate As opposed to each substrate formed in this 2nd body table the approach of repeating the process which forms the above-mentioned substrate, and the process which carries out image formation -- setting -- : -- In order to detect correlation of the location of the degree of complaint side which may show contamination or the structural defect of process; which makes the height map in which the height of two or more points on this substrate front face is shown, and the above-mentioned 2nd body table The approach characterized by having process; which compares the height map of the substrate obtained serially [claim 25] the radiation system (LA --) for being lithography projection equipment and supplying the projection beam (PB) of a radiation IL'; The 1st [equipped with the mask holder for holding a reflexibility mask (MA')], Movable body table (MT); Have a substrate holder for holding a substrate (W). Are related with the reference side of two or more points on the flat surface of the reflexibility mask which is projection equipment containing projection system (PL'); for carrying out image formation of 2nd body table (WT); and the irradiated part of this mask on the target part (C) of this substrate, and was held on the :above-mentioned mask holder. In a list, The height map creation means constituted and arranged so that height might be measured and the height map might be made; during exposure of the above-mentioned target part Equipment characterized by having control means; constituted and arranged so that the location in the 1st direction of the above of the above-mentioned 1st body table might be controlled at least according to the above-mentioned height map.

[Claim 26] the radiation system (LA --) for being the approach of manufacturing a device using the lithography projection equipment which has the following configurations, and supplying the projection beam (PB) of :radiation IL'; The 1st [equipped with the mask holder for holding a reflexibility mask (MA')], Movable body table (MT); a substrate (W) The substrate holder for holding projection system [for carrying out image formation of 2nd body table (WT); which it has, and the irradiated part of this mask on the target part (C) of this substrate] (PL'); -- process; which prepares the reflexibility mask (MA') which **** a pattern on the above-mentioned 1st body table -- a radiation induction layer on the above-mentioned 2nd body table In an approach including the process which carries out image formation of process; which forms the substrate (W) which it has, and the above-mentioned irradiated part of this mask on the above-mentioned target part of this substrate The :above-mentioned image formation process front, The approach which has the description in process; which positions this 1st body table in the 1st direction of the above at least with reference to the above-mentioned height map in process; which makes the height map about the reference flat surface on the above-mentioned 1st body table of two or more points on this mask front face in which height is shown, and the above-mentioned image formation process.

[Translation done.]

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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] This invention relates to height detection and leveling of a substrate and/or a mask in lithography equipment. Furthermore, the 1st body table which this invention is lithography projection equipment and is equipped with the mask holder for holding the radiation system; mask for supplying the projection beam of :radiation in detail; The 2nd [equipped with the substrate holder for holding a substrate], Movable body table; projection system [for carrying out image formation of the irradiated part of this mask on the target part of this substrate];, and the above-mentioned 2nd body table It is related with the system for off axis leveling in the projection equipment containing positioning system; for moving between the exposure location where the above-mentioned mask part is made in image formation by the above-mentioned projection system on the above-mentioned substrate, and a measuring point.
[0002]
[Description of the Prior Art] since it is easy, although this projection system may be henceforth called a "lens" --; -- it should be widely interpreted as this vocabulary including the projection system of the various types containing for example, a refractility optical element, a reflexibility optical element, a reflective refractility optical element, and a charged-particle optical element. You may follow for any of these principles being, the component which acts in order to point to the projection beam of a radiation and to fabricate or control it may also be included, and such a component may also call this radiation system a "lens" collectively or independently below. Moreover, you may also call this 1st and 2nd body table a "mask table" and a "substrate table", respectively. Furthermore, the thing of a type which has two or more mask tables and/or two substrate tables or more is sufficient as this lithography equipment. With such "multistage" equipment, an additional table may be used for juxtaposition, or a preparation process may be carried out on one or more tables, and, on the other hand, other one or more tables may be used for exposure.
[0003] Lithography projection equipment is applicable to manufacture of an integrated circuit (IC). In such a case, a mask (reticle) may also contain the circuit pattern corresponding to each layer of this IC, and can carry out image formation on the exposed region (die) of the substrate (silicon wafer) which applied this pattern in the layer of sensitive material (resist). Generally, the sequential exposure of every one them is carried out at once through reticle including all the networks of the die with which one wafer adjoins. exposing all reticle patterns at once on a die in one type of lithography projection equipment -- each die -- irradiating --; -- such equipment is usually called a wafer stepper. In the alternate device usually called step - and - scan equipment If this reticle pattern is sequentially scanned to the reference direction (the "scan" direction) given with the projection beam, this projection system generally considers as a scale factor M (generally <1) on the other hand and it is the rate nu which scans a wafer table Each die is irradiated by scanning a wafer table in this direction synchronizing with parallel or reverse parallel at the rate which scans the reticle table which scale-factor M Is the rate to apply. The further information about lithography equipment which was explained here is collectable from international patent application WO 97/33205.
[0004] Lithography equipment contained the single mask table and the single substrate table till recently [pole]. However, please refer to the multistage equipment with which the machine which now has at least two independently movable substrate tables is indicated by available; WO 98/28665, for example, international patent application, and WO 98/40791. Such the basic principle of operation of multistage equipment in back In order to expose the 1st substrate which has the 1st substrate table on it, while being under a projection system The 2nd substrate table can move to a loading location, discharge the exposed substrate, and a new substrate is taken up. Shortly after performing some initial measurement to this new substrate and then completing exposure of the 1st substrate, it is standing by in order to transport this new

substrate to the exposure location under a projection system, and repeating;, then this cycle. Thus, it is possible to improve the throughput of a machine considerably and the cost of ownership of this machine is improved as a result. He should understand that this same principle can be used only for one substrate table which moves between an exposure location and a measuring point.
[0005] The measurement performed to a substrate by this measuring point may also include the decision of the space relation between at least one reference marker located in the outside of the reference marker on the exposed region which the versatility for example, on a substrate ("die") means, and a substrate, and the substrate field on a substrate table (for example, criteria) (X and the direction of Y). in order that the exposed region about a projection beam may make such information quick and it may perform exact X and Y positioning behind -- an exposure location -- it can be used --; -- the further information -- for example, WO99 / 32940 (P-0079) reference. On these descriptions, Z location on the front face of a substrate in various points is related to the reference side of a substrate holder, and preparation in the point of measurement of a height map is also indicated. However, this reference side is defined with Z interferometer by the measuring point, and another Z interferometer is used for it in an exposure location. Therefore, it is required to get to know the exact relation between the zeros of two Z interferometers.
[0006]
[Problem(s) to be Solved by the Invention] The object of this invention is offering the system for carrying out off axis leveling of a substrate which avoids the need of connecting the zero of two interferometer systems, and enables an additional improvement of positioning of an exposed region in an exposure process in lithography projection equipment.
[0007]
[Means for Solving the Problem] The 1st body table which according to this invention is lithography projection equipment and is equipped with the mask holder for holding the radiation system; mask for supplying the projection beam of :radiation; Have a substrate holder for holding a substrate. The 2nd movable body table; projection system [for carrying out image formation of the irradiated part of this mask on the target part of this substrate];, and the above-mentioned 2nd body table It has the physical reference side where the 2nd body table of; above was fixed to it in the projection equipment containing positioning system; for moving between the exposure station where the above-mentioned mask part is made in image formation by the above-mentioned projection system on the above-mentioned substrate, and a measurement station. In a list :projection equipment Two or more points on the front face of the substrate which was located in the above-mentioned measurement station and held on the above-mentioned substrate holder, The height map creation means about the above-mentioned physical reference side constituted and arranged so that height might be measured and the height map might be made; It is located in the above-mentioned exposure station. In a list, The location measurement means for measuring the location in the 1st vertical direction substantially on the above-mentioned substrate front face of the above-mentioned physical reference side, after moving the above-mentioned 2nd body table to the above-mentioned exposure station; during exposure of the above-mentioned target part The equipment characterized by having the control means constituted and arranged so that the location of the above-mentioned 2nd body table in the 1st direction of the above might be controlled at least, and; according to the above-mentioned location measured with the above-mentioned height map and the above-mentioned location measurement means is offered.
[0008] The 1st body table equipped with the mask holder for holding the radiation system; mask for supplying the projection beam of a radiation according to the further mode of this invention; Have a substrate holder for holding a substrate. The 2nd, Movable body table; and the irradiated part of this mask On the above-mentioned 2nd body table, The process which prepares the mask which is the manufacture approach of the device using the lithography projection equipment containing the projection system for carrying out image formation on the target part of this substrate at an exposure station, and **** a pattern on the 1st body table of :above; a radiation induction layer In an approach including the process which carries out image formation of process; which forms the substrate which it has, and the above-mentioned irradiated part of this mask on the above-mentioned target part of this substrate The :above-mentioned image formation process front, This 2nd body table is in a measurement station. Two or more points on this substrate front face, The process which makes the height map about the physical reference side on the above-mentioned 2nd body table in which height is shown; This 2nd body table is moved to the above-mentioned exposure station. In a list, The process which measures the location in the 1st vertical direction substantially on the above-mentioned substrate front face of the above-mentioned physical reference side; in the above-mentioned image formation process The approach the description is in the process which positions this 2nd body table in the 1st direction of the above at least with reference to the above-mentioned

location measured in the 1st direction of the above of the above-mentioned height map and the above-mentioned physical reference side is offered.
[0009]
[Embodiment of the Invention] In the manufacture process using the lithography projection equipment by this invention, image formation of the pattern of a mask is carried out on the substrate selectively covered with the energy sensitivity ingredient (resist) at least. Before this image formation process, this substrate may receive various processings like an under coat, resist spreading, and software BEKU. A substrate may receive other processings like measurement/inspection of for example, after [exposure] BEKU (PEB), development, postbake, and an image formation gestalt after exposure. This the processing of a series of is used as a foundation for patternizing each layer of a device, for example, IC. The layer patternized such may receive next various processings of etching, an ion implantation (doping), metalization processing, oxidation treatment, chemistry, mechanical polish, etc., etc. in which finishing of each layer was meant altogether. If some layers are required, all processings or deformation of those will have to be repeated to each ********. After all, the array (die) of a device is made on a substrate (wafer). Next, these devices are separated from each other by dicing or technique like sawing, and anchoring and a pin can be connected to a carrier for each device from there. The further information about such a process can be acquired from books, such as ISBN 0-07-067250-4, in "the practical use guide of fabrication:semi-conductor processing of a microchip" of Peter Van ZANTO, the 3rd edition, a tuna UHIRU publishing company, and 1997.
[0010] Although the text may explain especially in order to use the equipment by this invention for manufacture of IC, he should understand clearly that the possibility of many of other applications is in such equipment. For example, it may be used for manufacture of an integrated optics system, the induction detection pattern for magnetic-domain memory, a liquid crystal display panel, the thin film magnetic head, etc. Probably, it turns out [of vocabulary called the "reticle", the "wafer", or the "die" which this contractor uses in this text due to such an alternative application] that it should be considered for which that it is replaced by each in the respectively more general vocabulary "a mask", a "substrate", and a "exposed region."
[0011] On these descriptions, although ultraviolet rays (for example, wave section (365nm, 248nm, 193nm, 157nm, or 126nm)), extreme ultraviolet rays (EUV), an X-ray, an electron, and ion are included using the vocabulary a "radiation" and a "beam", all kinds of the electro magnetic radiation or particle flux which is not limited to it is included. Too, this invention is explained using the reference frame of rectangular crosses X and Y and a Z direction, and the revolution of the circumference of a shaft parallel to the direction of I is expressed with Ri here. furthermore -- since it requires that the context should be another -- if -- it uses here -- "vertical" -- the vocabulary (Z) points out a direction vertical to a substrate or a mask side rather than means any of this equipment, or a specific direction.
[0012]
[Example 1] With reference to an example and an attached schematic diagram, this invention is explained below. Drawing 1 shows the lithography projection equipment by this invention roughly. This equipment is :-. Radiation systems LA, Ex, IN, and CO for supplying the projection beam PB of a radiation (for example, UV or EUV);
- The 1st body table MT combined with the 1st positioning means for having a mask holder for holding Mask MA (for example, reticle), and positioning this mask to accuracy about Member PL (mask table);
- The 2nd body table WTa combined with the 2nd positioning means for having a substrate holder for holding Substrate W (for example, silicon wafer which applied the resist), and positioning this substrate to accuracy about Member PL (a substrate or wafer table);
- The 3rd body table WTb combined with the 3rd positioning means for having a substrate holder for holding Substrate W (for example, silicon wafer which applied the resist), and positioning this substrate to accuracy about Member PL (a substrate or wafer table);
- Gaging-system MS; and - for performing a measurement (property display) process on the substrate held on the substrate table WTa or WTb at the measurement station Projection system ("lens") PL(for example, system [of refraction or reflective refractility], Mirror Group Newspapers, or field-of-view deflecting-system array); for carrying out image formation of the irradiated part of this mask MA on the exposed region C of the substrate W held at the exposure station at the substrate tables WTa or WTb (die) is included.
[0013] This equipment is a transparency mold as shown here (that is, it has a transparency mold mask). However, generally for example, a reflective mold is sufficient as it.
[0014] This radiation system includes the line source LA (for example, the undulater and the source of the

laser plasma which were established in the surroundings of the path of the electron beam of a mercury lamp, the Examiner laser, a storage ring, or a synchrotron, an electron, or the source of an ion beam) which makes the beam of a radiation. The optic, - Ex, for example, the beam shaping optical element, Integrator IN, and Capacitor CO of the versatility contained in this lighting system in this beam - It lets it pass and is made for the made beam PB to have a desired configuration and the intensity distribution in that cross section.
[0015] This beam PB crosses the mask MA currently held continuously at the mask holder on the mask table MT. After passing Mask MA, Beam PB passes Lens PL and the lens converges Beam PB on the exposed region C of Substrate W. An exposed region C which can move the substrate tables WTa and WTb to accuracy with the 2nd and 3rd positioning means, for example, is different is arranged in the path of Beam PB using interferometer displacement and the measurement means IF. Similarly, after taking out Mask MA mechanically from a mask library, using the 1st positioning means, this mask MA can be arranged to accuracy about the path of Beam PB. Generally, migration of the body tables MT, WTa, and WTb is realized using a long stroke module (rough positioning) and a short stroke module (detailed positioning), although there is no ****** in drawing 1 clearly. the case of a wafer stepper -- (-- step - and - scan equipment -- being different --) -- a reticle table may be combined only with a short stroke pointing device, and the sense of a mask and detailed adjustment of a location may be performed.
[0016] This 2nd and 3rd positioning means may be constituted so that each of substrate tables WTa and WTb of them can be continued and positioned in the range including both the exposure station under the projection system PL, and the measurement station under gaging-system MS. Instead, you may replace with the table exchange means for exchanging these substrate tables for the separate exposure station for positioning a substrate table for this 2nd and 3rd positioning means to each exposure station, and a measurement station positioning system list between two positioning systems. The suitable positioning system is especially indicated by above WO 98/28665 and WO 98/40791. The number of measurement stations may differ from the number of exposure stations mutually in that you may have a multistage exposure station and/or a multistage measurement station and a list, and the total of a station should notice lithography equipment about that it does not need to be equal to the number of substrate tables. The principle which makes exposure and a measurement station separate actually holds good also in a single substrate table.
[0017] The equipment to illustrate is :1. which can be used in the two different modes. In step-and-repeat (step) mode, it fixes intrinsically, the mask table MT is held, and all mask images are projected at once on an exposed region C (with namely, single "a flash plate"). Next, it enables it to irradiate an exposed region C which moves the substrate table MT in X or the direction of Y, and is different by Beam PB, and is;2. In step - and - scan (scan) mode, the same scenario is intrinsically applied except for not exposing the given exposed region C by the single "a flash plate." Instead, it can move in the direction (the so-called "scan" direction of Y, for example, the direction) in which the mask table MT was given at a rate v, and while making the projection beam PB scan a mask image top and; Curving, the substrate tables WTa or WTb are moved simultaneous [to an opposite direction / at the rate of V=Mv] similarly. However, M is the scale factor (typically M= 1/4 or 1/5) of Lens PL. Thus, it is not necessary to compromise on resolution and the comparatively big exposed region C can be exposed.
[0018] The important factor which influences the image formation quality of lithography equipment is a precision which converges a mask image on a substrate. The range for adjusting the location of the focal plane of the projection system PL is restricted actually, and since the depth of focus of the system is shallow, this means that the exposed region of a wafer (substrate) must be arranged to the focal plane of the projection system PL at accuracy. In order to carry out this, of course, it is necessary to get to know both the location of the focal plane of the projection system PL, and the location of the top face of a wafer. Although a wafer is ground to super-high flatness, the deviation ("the degree of complaint side" is called) from the perfect flatness on the front face of a wafer of sufficient magnitude to influence for focal precision notably may take place. The degree of complaint side may be produced with the dirt of the distortion or the wafer holder of dispersion for example, in wafer thickness, and a wafer configuration. Existence of the structure by previous down stream processing also influences the height (flatness) of a wafer considerably. By this invention, the cause of the degree of complaint side is mostly unrelated, and considers only the height of the top face of; wafer. In not mentioning specially, the "wafer front face" called below points out the top face of a wafer which projects a mask image on it.
[0019] According to this invention, after loading a substrate table with a wafer, height ZWefer on the front face of a wafer to the physical reference side of this substrate table is used as a map. This process is a measurement station and is performed by measuring the vertical (Z) location of this physical reference side,

and the vertical position ZLS on the front face of a wafer in respect of plurality using the 1st sensor called a level sensor, and measuring the vertical position of this substrate table, and ZIF simultaneously at the same point using the 2nd sensor, for example, Z interferometer, in a list. As shown in drawing 2 , wafer surface height is determined as ZWefer=ZLS-ZIF. Next, the substrate table which **** this wafer is moved to an exposure station, and the vertical position of a physical reference side is determined again. Next, in case a wafer is positioned in an exposure process at a right vertical position, this height map is referred to. This procedure is explained in more detail with reference to drawing 3 thru/or drawing 6 below.

[0020] As shown in drawing 3 , a substrate table is first moved, as the physical reference side fixed to this substrate table is under a level sensor LS. X on a substrate table, Y, and some Z locations are good for them in respect of being convenient, if this physical reference side does not change under processing of the wafer in this lithography equipment, and to the most important thing in the case of migration between a measurement station and an exposure station of a substrate table. This physical reference side should have a property which some criteria including other alignment marks are [property] sufficient, and makes that vertical position measure by the same sensor as measuring the vertical position on the front face of a wafer. In the example suitable now, this physical reference side is a reflector of the criteria which insert the so-called transparency mold image sensors (TIS) in inside. Below, this TIS is explained further.

[0021] a photosensor which is indicated by U.S. Pat. No. 5,191,200 (P-0039) (a focal error detection system is called in it) is sufficient as this level sensor, and it can consider; instead pneumatic pressure, or a capacity sensor (for example). The form of the sensor using the moire graphic form made between the image of the projection grid reflected according to the wafer side and the fixed detection grid suitable now is explained in relation to the 2nd example of this invention below. This level sensor may measure the vertical position of two or more locations simultaneously, and may measure the average height of a small area to each, and may average the degree of complaint side of height spatial frequency.

[0022] To the measurement and coincidence of the vertical position of a physical reference side by the level sensor LS, the vertical position of a substrate table and ZIF are measured using Z interferometer. Some of 3 which are indicated by WO 99/28790 (P-0077), or WOPP/32940 (P-0079), 5, or 6 shaft interferometer type instrumentation systems are sufficient as this Z interferometer. As for these Z interferometer systems, it is desirable to measure in that it has the same location as the measuring point to which the level sensor LS proofread the vertical position of a substrate table at XY flat surface. This may measure the vertical position by the side of [which counters] two of the substrate tables WT at the point which is in agreement with the measuring point of this level sensor, and may perform between them interpolation / by carrying out modeling. This guarantees that this Z interferometer measurement shows surely the vertical position of the substrate table under a level sensor, when a wafer table inclines from XY flat surface.

[0023] this process -- the [this] -- it estranged in diagonal line from 1 physical reference side, for example -- at least -- the -- it is desirable to repeat in respect of 2 physical reference. Then, a reference side can be defined using the height measurement from two or more locations.

[0024] The coincidence measurement of the vertical position of one or more physical reference sides and the vertical position of a substrate table establishes the point of deciding the reference flat surface used as the criteria which should use wafer height as a map. Z interferometer of the above-mentioned class -- absolutely -- a sensor -- as a matter of fact -- a variation rate -- although it is a sensor, then zero doubling is required, it continues broadly and altitude is provided with linear location measurement. on the other hand, although a suitable level sensor, for example, the above-mentioned thing, offers location measurement absolutely about the reference flat surface (namely, nominal zero) decided outside, it continues and comes out of it to the small range. When using such a sensor, it is convenient to move a substrate table vertically until a physical reference side is located in nominal zero in the medium of the measuring range of a level sensor, and to read a current interferometer Z value. These one or more measurement about a physical reference side will establish the reference flat surface for height map creation. Next, Z interferometer is set by zero about this reference flat surface. Thus, this reference flat surface is connected with the physical side on a substrate table, and a ZWefer height map is made regardless of other local factors like the degree of complaint side of the base plate to which the initial zero location and substrate table of Z interferometer in a measurement station are moved. Moreover, this height map is made regardless of the drift of the zero location of a level sensor.

[0025] A substrate table is moved so that a wafer side may be scanned under a level sensor in order to make a height map once it establishes this reference flat surface, as shown in drawing 4 . The vertical position of a wafer side and the vertical position of a substrate table are measured in respect of the plurality of known XY location, it lengthens from each other, and the wafer height in known XY location is obtained. These wafer

height values can form a wafer height map, and can record it in a suitable form. For example, these wafer height values and XY coordinate may be memorized to the pair which does not look together to the so-called eye. Instead, by scanning a wafer at the rate of predetermined in accordance with a predetermined path, and measuring the point which takes a wafer height value at the predetermined spacing, it decides beforehand and carries out as [fully / for the array of a simple list or a height value determining this height map (parameter of the fraction which decides a measurement pattern and/or a start point to be arbitration)].
[0026] A great portion of motion of the substrate table under height map creation scan is only in XY flat surface. However, if a level sensor LS is the type of offering only positive zero reading, in order to maintain a wafer side at the zero location of this level sensor, also vertically, a substrate table is moved. Then, it guides intrinsically from Z motion of the substrate table which measured wafer height with Z interferometer required in order to maintain zero reading from a level sensor. However, it is desirable to use a level sensor with a quite wide measuring range which an output can linearize with regards to wafer height and linearity. Ideally, such a measuring range includes the maximum prediction of wafer height, or a permissible variation. According to such a sensor, since it is not by the capacity of a short stroke substrate table for a scan speed to pursue the profile of a wafer by the three dimension and is restricted by the response time of a sensor, the need for vertical motion of the substrate table under this actuation decreases, or is lost, and can finish a scan quickly. Moreover, the large sensor of a proportional region enables it to measure height simultaneously in two or more locations (for example, array of a point).
[0027] Next, as a wafer table is moved to an exposure station and it is shown in drawing 5 , this (physical) reference side is arranged under a projection lens, and it can be made to perform measurement of that vertical position to the focal plane of this projection lens. In the suitable example, this attains the detector using one or more transparency mold image sensors (it explains below) physically combined with the reference side used by pre- measurement. These transparency mold image sensors can determine the vertical focus location of the image projected from the mask under a projection lens. The path for the substrate table in the three dimension which can prepare this measurement, and can connect this reference flat surface with the focal plane of a projection lens, and maintains a wafer side at the optimal focus can be decided. One method of performing this is calculating Z and Rx to a point, and Ry set point of a single string in alignment with this scan path. These set points decide to make the difference between wafer map data and the focal plane of an exposure slit image into min using a least square method. In order to make count easy, the relative motion of an exposure slit image and a wafer can be expressed under the condition that a slit moves to a static wafer. Then, these least square criteria are : [0028] which can be expressed as finding the value of Z (t) which gives the minimum value of the following formula, Rx (t), and Ry (t) to each time amount t.
[Equation 1]

$$LSQ(t)=\frac{1}{s}\cdot\frac{1}{W}\int_{-\frac{s}{2}}^{\frac{s}{2}}\int_{-\frac{W}{2}}^{\frac{W}{2}}[w(x,y)-(Z(t)+x\cdot Ry(t)-y\cdot Rx(t))]^{2}dxdy \qquad [1]$$

However, w (x y) is a wafer height map, exposure slits are the width of face s of a scanning direction, and the rectangle flat surface of die-length W vertical to this scanning direction, and that location is defined by Z (t), Rx (t), and Ry (t). Being able to express these set points and a wafer path as a function of Y (location of a scanning direction), or t (time amount), that is because these are connected by Y=y0+vt. However, y0 is a start point and v is a scan speed.
[0029] As mentioned above, a physical reference side has the desirable field which inserts transparency mold image sensors (TIS) in inside. As shown in drawing 7 , Wafer W attaches two sensors TIS1 and TIS2 in a mounting beam criteria plate on the top face of a substrate table (WT, WTa, or WTb) in the location which counters the outside of a wrap field in diagonal line. This criteria plate is made from the ingredient dramatically stabilized highly in the low coefficient of thermal expansion, for example, umber, has a flat reflective top face, and may **** the mark which it uses in an alignment process. TIS1 and TIS2 are sensors used in order to measure directly the vertical (and horizontal) location of the air image of a projection lens. The photodetector which induces the radiation which uses them for each front face for exposure processes in the back near it including opening is arranged. In order to decide the location of a focal plane, a projection lens projects the image of pattern TIS-M of TIS which prepares on Mask MA and has ** and a dark contrast field on space. next, it scans vertically and is made to pass a substrate stage through a horizontal and the space where opening of TIS is predicted that there is this air image (one direction -- or -- desirable -- a 2-way) TIS opening's passage of ** and dark space of the image of a TIS pattern will fluctuate the output of a photodetector. The vertical level whose amplitude photodetector output change rate is max shows the level

on which the image of a TIS pattern has the greatest contrast, therefore shows the flat surface of the optimal focus. The example of this kind of TIS is dramatically indicated by U.S. Pat. No. 4,540,277 at the detail. Instead of TIS, reflective image sensors (RIS) which are indicated by U.S. Pat. No. 5,144,363 may also be used.

[0030] Using the front face of TIS as a physical reference side has the advantage that TIS measurement connects directly the reference flat surface used for a height map with the focal plane of a projection lens, then a height map can be directly used for it, in order to give height amendment into an exposure process for a wafer stage. This is illustrated to drawing 6 , and it shows the substrate table WT positioned under control of Z interferometer in the height decided on the height map, as a wafer front face is located in the right location under the projection lens PL.

[0031] This TIS front face may **** a reference marker additionally, may detect that location using a TTL (it lets lens pass) alignment system, and may align a substrate table on a mask. Such an alignment system is indicated by for example, EP-0,467,445A (P-0032). Alignment of each exposed region can also perform an exposed region in the alignment procedure which carries out on a measurement stage in order to align at the reference marker on a wafer stage, or may be made unnecessary by it. Such a procedure is indicated by for example, EP-0906590A (P-0070).

[0032] Probably, by the production process, it turns out in both the modes of step-and-repeat and step - and - scan that the mask image projected by the projection system PL continues and spreads to a remarkable field not at a single point but at XY flat surface. Since wafer height may cover this field and may vary considerably, it is desirable to continue and optimize focusing not only to a single point but to this whole projection field. In the example of this invention, this can be attained, when not only the vertical position of the substrate table WT but the inclination (Rx, Ry) of the circumference of the X and a Y-axis controls. The location and range of an exposed region to mean are got to know, and Optima Z and Rx and Ry set point of a substrate table to each exposure can be beforehand calculated using the height map made by this invention. This omits time amount required when a wafer is located under a projection lens, in order to level with the known equipment which measures only wafer height, therefore increases a throughput. Using the known various mathematical technique, an interactive process may be used for Optima Z and Rx and Ry set point, and they may calculate it by making into min the focal gap with which it continued and integrated to the whole exposed region (a definition being given as a distance between a wafer front face and an ideal focal plane), i.e., LSQ, (t).

[0033] The further advantage is possible in step - and - scan mode. In this mode, a projection lens projects some images of a mask pattern on the part to which an exposed region corresponds. Next, this mask and substrate are synchronously scanned from the body of the projection system PL, and the edge of an image focal point side to an edge, and image formation of all the mask patterns is carried out on [all] an exposed region. Although a projection lens is fixed and a mask and a substrate are moved actually, it is often convenient to transpose this process to the image slit which moves on a wafer front face, and to consider it. It is possible to calculate a series of Z, Rx(es), and Ry set points which are the height map decided beforehand and are adjusted by this invention for XY scan path (a scan is usually performed to an one direction, for example, Y). This set point of a series of can be optimized by making into min the normal acceleration or titing which may carry out induction of the increase of a throughput, or the oscillation which is not desirable by additional criteria. Supposing it can give a series of estranged set points, the scan path over exposure is calculable using a polynomial or a spline adaptation procedure.

[0034] Although it means arranging a wafer in the optimal location by Z, Rx, and Ry to the given exposure, since the whole exposed region is covered and wafer height is changed, this invention may be unable to be arranged so that focusing of the wafer may fully be carried out over all fields. Such so-called focal spot may produce poor exposure. However, such nonconformity can be beforehand predicted by this invention, and restoration can be performed. for example, -- without it removes a wafer and carries out the adverse effect of the wafer of poor exposure to the further processing -- ****** -- things are made. Instead, the defect who predicted influences only one or few devices on this wafer, but if others are acceptance, they may improve a throughput by flying the exposure which can be predicted that a defect device is made beforehand.

[0035] The further advantage of focal spot detection can be acquired from the analysis of the made height map. When that it is only serious from a global wafer side exists in a wafer height map, this may show the degree of substrate complaint side, or the focal dirt under process effect. The comparison of the wafer height map from some wafers can show the focal dirt by contamination of a substrate table, or the degree of complaint side. When appearing in the same or, almost same location to the wafer with which focal dirt differs, this has highest possibility of being generated by substrate holder contamination (the so-called

"chuck dirt"). From one wafer height map, the height map (topology) from the exposed region (die) to repeat can also be compared. If a big difference arises in a certain die about an average height map, the focal dirt on wafer processing or a substrate table can be suspected. Instead of comparing a wafer height map, the same comparison can also be performed about the induction exposure path per die, the focal gap parameters MA and MSD which are explained below, or a migration focus. A focal spot can also be detected when a certain die or wafer separates greatly from an average exposure path or a focal gap parameter.

[0036] Before all the analyses described above expose a wafer, they can be performed, and restoration like wafer abatement (effect of processing) or substrate holder cleaning (chuck dirt) can be performed. By these approaches, it can localize to the magnitude of the point of measurement of the focal spot level sensor 10. This means the resolution higher than the conventional approach of focal spot detection for whether your being Haruka.

[0037]

[Example 2] The 2nd example of this invention is shown in drawing 8 , and, as for it, only an exposure station and a measurement station show only the components relevant to the following arguments to a list. This 2nd example uses the leveling principle of this invention explained above with a certain amelioration explained below.

[0038] The mounting beam projection lens PL shows projecting the image of TIS marker TIS-M on Mask MA on the wafer table WT on the mounting beam sensor TIS to the measurement frame MF at the exposure station on the left of drawing 8 . This measurement frame is isolated from transfer of the oscillation of this equipment from other components, and only the passive components used for detailed measurement and alignment detection are carried on it. This whole measurement frame may be made from the very small ingredient of a coefficient of thermal expansion like umber so that this equipment may also change with the very stable platform of the most sensitive measurement component. There are mirrors 34 and 35 in the components attached on this measurement frame MF, and the measurement beam ZIF of Z interferometer is led to the side face of the wafer table WT by the 45 degree mirror 31 of mounting beams at it. In order to guarantee that Z location of a substrate table can be continued and measured in the motion range of the X, mirrors 34 and 35 have big breadth in the direction of X. In order to guarantee that this Z location can be continued and measured in the range of Y motion, a mirror 31 covers the overall length of a wafer table. Beam generating and the receipt components 21a and 22a of reliance sensor 20a which are explained in detail below are too attached in the measurement frame MF.

[0039] since the same measurement frame MF **** the mirrors 33 and 32 which achieve the same function as the mirrors 34 and 35 of an exposure station and mirrors 32 and 33 also correspond to the required motion range of the substrate table WT at a measurement station (it is the right at drawing 8) -- an exposure station -- completely -- the same -- it has the big breadth of the direction of X. The level sensor 10 containing the beam generating components 11 and the detecting-element article 12 is also attached on the measurement frame MF. Moreover, it has the same reliance sensor 20b as reliance sensor 20a of an exposure station intrinsically. It can prepare, other measuring devices, for example, alignment module.

[0040] As argued above, using a physical reference side (this being given by the top face of TIS also in this example) relates a wafer height map with a wafer stage, and it makes it unrelated to a certain local factor like the degree of complaint side of the base plate (stone) BP with which the zero location of two Z interferometers moves it, and a wafer table moves a top. However, since it controls using another Z interferometer which then, made the wafer height map at the measurement station using Z interferometer, and prepared the substrate table location at the exposure station, the precision to which a certain difference as a function of XY location between two Z interferometers arranges a wafer side to a focal plane may be influenced. The main factor of these fluctuation by the interferometer systems of the class used by this invention is the degree of complaint side of mirrors 32, 33, 34, and 35. Anchoring and it move the 45-degree mirror 31 to the wafer table WT with it, when a location replaces between an exposure station and a measurement station. therefore, the degree of complaint side of these mirrors is the same as a measurement station to positioning at an exposure station -- extent effect is carried out and it is fully removed. However, if the mounting beam mirrors 32, 33, 34, and 35 pile up with each interferometer of them, then a difference is in matched pairs 32 and 34 and 33 or 35 surface profiles on the measurement frame MF, an adverse effect may be carried out to the vertical-position arrangement precision of the substrate table WT.

[0041] The check sensors 20a and 20b are used for initial setting of this equipment, are used if needed periodically after that, and proofread the difference between Z interferometers at a measurement station and an exposure station. These check sensors are sensors which can be measured at one or more points, when scanning a substrate table for the vertical position of the top face of a wafer in the bottom of it. Although the

reliance sensors 20a and 20b can make a design the same as a level sensor 10, since it is not necessary to do them so and they use only setting out for; list not with a production wafer but with a reference wafer (to and rare recalibration), its design basis is not troublesome and they can design a simple sensor using this. On the contrary, that the projection lens PL exists in an exposure station needs to restrict the physical location which can be used for a check sensor at the station, and it also needs to take this into consideration to a design or selection of each check sensor. Since the calibration using a check sensor influences the quality of all exposure, high degree of accuracy is required of them.

[0042] A substrate table is loaded with a reference wafer in the calibration process using a check sensor. As for this reference wafer, it is desirable that it is a naked silicon wafer. although some flat demands do not have it from Si wafer of the usual nakedness -- the surface finish (at point of a reflection factor) -- optimizing to these reliance sensors is desirable. It is desirable to grind so that this reference wafer may make that reflection factor max and the degree of complaint side may be made into min in the suitable example of this invention.

[0043] The partial height map (it usually passes and is related to a physical reference side) of a reference wafer is made from a calibration procedure at a measurement station not using the level sensor 10 but using check sensor 20b. This is performed by the same approach as a level sensor 10, arranges; physical reference side (TIS) at the zero point of a reliance sensor, makes Z interferometer zero, then, scans a wafer under a reliance sensor, and makes a height map from the difference between readings of a check sensor and Z interferometer. A height map is made from the same point as the height map of a measurement station also at an exposure station using reliance sensor 20a. To this calibration, a height map does not need to scan a wafer thoroughly and only needs to cover the strip corresponding to motion of Z interferometer beam on the; mirror 32-35. (If the sequence which makes these maps is stability while a wafer performs both on a substrate table, it is not important.)

[0044] Probably, they were produced according to the difference between the gaging systems used in order to make them, when these maps had a difference among them, since they expressed the same wafer. Two reliance sensors are static, then normalization of two height maps instead of a location dependency and/or subtraction of an offset can remove the effect on those height maps. If there is a difference which remains, it is a location dependency, can lengthen two height maps from each other, and can make the amendment table (mirror map) which relates an exposure station Z interferometer with a measurement station Z interferometer. These amendment tables can be used in order to amend one of the Z interferometers used in order to be able to apply to the wafer height map which could consider that was as a result of the difference between the mounting beam mirrors 33, 35, and 32 and 34 on the measurement frame MF, then was made from the production process or to make a map, or in order to position a substrate table during exposure. The difference of Z location produced the degree of complaint side of the mirror of each interferometer systems by the precise structure especially measurement frame mirror, and substrate table mirror of Z interferometer may also be a dip dependency in one or more degrees of freedom (Rx, Ry, Rz). In order to abolish this dip dependency, the amendment table (mirror map) on which it may be the need on which making the height map of some [the wafer stage of the dip where versatility differs using a reliance sensor], and a large number differ if needed can be guided.

[0045] Since the principle of off axis leveling was explained, the nest approach to the production process is shortly explained to some of the further amelioration used in the 2nd example, and a list. Drawing 9 and drawing 10 show the process performed at a measurement station and an exposure station, respectively. With the lithography equipment which uses two wafer tables, one table performs the process of drawing 9 , and on the other hand, the 2nd table performs the process of drawing 10 simultaneously, before exchanging them. By the following explanation, the "life" of a single wafer continues until it goes and returns from a measurement station (drawing 9) to an exposure station (drawing 10).

[0046] It loads with the wafer applied to the process S1 of drawing 9 by **** and the photosensitive resist on the substrate table WT. (Generally the substrate table should notice this about that your may carry out at the loading station other than a measurement station which exists out of range [interferometer-systems IF].) The process S2 which moves this wafer table to prehension within the limits of one or more location detection equipments (PSD) so that it can perform initial rough zero setting an interferometer instrumentation system. Interferometer systems' zero doubling [detailed initialization /] continue by the process S3 and S4 after this initial rough zero doubling. Including the level sensor measurement ("LS" shows) on a physical reference side (two or more), it defines a reference flat surface (it fixed to the wafer table), and these two processes measure a wafer height map about it. Moreover, two alignment measurement ("AA" shows) is performed about the marker located on the same physical reference side, and the level

reference location fixed to the wafer table is defined. These measurement by S3 and S4 carries out zero doubling of these interferometer systems effectively with all degrees of freedom.
[0047] The next process in this leveling procedure is S5 called a global-area level profile (GLS). At this process explained in more detail below, the initial scan by the level sensor of wafer prehension and a wafer is performed, and the height in the greater part of that point that a next detail scan frequents the height of that whole and dip, and a list at this wafer is decided. This information enables it to decide the substrate table trajectory for a wafer height map scan.
[0048] Global-area alignment of a wafer is performed at a process S6. At least two alignment markers on a wafer are measured (W1 and W2), and it means that those XY locations were decided about the reference marker on TIS criteria. This determines extent (Rz) which rotates a wafer horizontally about a scanning direction (y), and like, since [which performs a wafer height map scan to parallel at an exposed region shaft (that is, "an exposed region top is gone straight on")] a revolution of a wafer can be amended, it performs it.

[0049] Then, this leveling procedure continues measurement required for processing dependence amendment (PDC). Processing dependence amendment is required of a form with a level sensor, and is explained below.
[0050] A wafer height map must be made every, whenever it exposes a wafer. If the wafer has already received one or more down stream processing, this surface layer may also have the topology showing not already pure polished silicon but the structure already made on this wafer, or the already made gestalt. A different surface layer and structure may influence reading of a level sensor, and the linearity may be changed especially. ********** [effects / these effects may be based on the diffraction operation produced according to a surface structure, may be based on the wavelength dependency of a surface reflection factor, and] whenever this level sensor is optical. In order to opt for required processing dependence amendment, the substrate table WT is set as the vertical position from which some covering the linearity or the linearization range of a level sensor 10 differ, and an exposed region or a die is operated under this level sensor. the physical distance between wafer height, i.e., a wafer front face and a reference flat surface, -- the vertical position of a substrate table -- it should not change --; -- :ZWAFER=ZLS-ZIF obtained when it lengthens the measured value of a level sensor and Z interferometer. Therefore, if the value which ZWAFER determined does not change by the vertical position of a substrate table, this means that either a level sensor or Z interferometer and both are not linearity, or it is not a ** scale. Since Z interferometer looks at the mirror on a wafer table and a measurement frame, when it is thought that it is linearity and; actuality and the amendment for which it once opted by the activity of a check sensor at least are applied, it is linearity from a precision required for a wafer map at altitude. Therefore, if a difference is in a wafer height value, it will be assumed that it was produced from the nonlinearity or the scale error of a level sensor. The output of this level sensor can be amended using the information of reading of the level sensor when observing them and them. In the example of this level sensor suitable now, although simple gain amendment was enough, it turned out that still more complicated amendment may be the need at other sensors.
[0051] it has the exposed region where the wafer which should be processed has received another processing on it -- if it becomes -- this wafer top -- each -- ** -- it opts for processing dependence amendment to the exposed region of a type. On the contrary, what is necessary is just to measure processing dependence amendment to the exposed region of 1 time various kinds per batch, if it is the same or the batch of the wafer which has a carrier beam exposed region for similar processing should be exposed. Then, the amendment is [every] applicable whenever it makes the height map of the kind of exposed region from a batch.
[0052] In many IC manufactures, just before loading lithography equipment with a wafer, a photosensitive resist is attached to it. In the reason of this or others, a wafer may be different temperature from a substrate table, when it loads and clamps in a proper place. Since the wafer is clamped very firmly using vacuum attraction when a wafer gets cold to the same temperature as a substrate table (or it got warm), thermal stress may arise. These may produce distortion which is not desirable as for a wafer. Thermal equilibrium is likely to be attained [by] when a process S2 thru/or S7 finish. Therefore, at a process S8, the vacuum clamp to the substrate table of a wafer is released, the thermal stress of a wafer is loosened, and then it re-applies. Although this relaxation may produce a small change in the location and/or dip of a wafer, a process S2 thru/or S4 are unrelated to a wafer, and since S5 and S6 are only rough measurement, these are permissible. Since it is not measurement of a wafer but the calibration of a level sensor, change of the wafer location in this phase does not influence processing dependence amendment.

[0053] It is not again released until it completes an exposure process for a vacuum henceforth after re-application and performs Z map by process S9. A scan required for this Z map must measure the height of sufficient point so that a wafer can be arranged in a desired precision during exposure. The measured point is important also for covering the actual field which should expose a wafer,; mark attachment lane and the so-called rat may bite, and the measurement covering a non-exposed region like a blemish may produce the result which invites misunderstanding. Therefore, a height map creation scan must be optimized to the specific pattern of the exposed region on a wafer at hand, and explains this below to; in more detail.
[0054] Once Z map is completed, after performing precedence alignment measurement and a process S10, a substrate table will be exchanged to an exposure location at a process S11. In this precedence alignment process, the location of many alignment markers on a wafer to the reference marker located on the TIS criteria (physical reference side) fixed to the substrate table is determined as accuracy. This process is not explained here any more especially without relation to this invention.
[0055] In an exchange procedure, the substrate table which **** the wafer which made the height map arrives at an exposure station. The process S13 of drawing 10 . Rough fixing of a substrate table is performed at a process S14, and if , the mask table MT is loaded with the new mask MA. Process S15. This mask loading process may be performed to substrate table exchange and coincidence, or may be begun at least. If a proper place once has a mask and it stops by performing rough fixing and a process S14, the 1st TIS scan will be performed using a sensor TIS1 at a process S16. As this TIS scan was explained above, this TIS measures vertical and the horizontal position of a substrate table which are located in the air image focal point of a projection lens, and brings about "refer to the focal plane." Since the height map made from process S9 of drawing 9 is connected with the physical front face in which TIS is located, the direct lead of the vertical position of a substrate table required in order to establish a wafer front face in a focal plane to another exposed region is carried out. The 2nd TIS scan and a process S17 are also performed using a sensor TIS2, and the 2nd point for referring to a focal plane is acquired.
[0056] If a TIS scan is once completed and a focal plane is determined, the exposure process S18 will be performed after a system calibration (for example, adjustment for amending the lens heating effectiveness) required for the arbitration in a process S19. Generally this exposure process is accompanied by exposure of two or more exposed regions using one or more masks. When using two or more masks, after the mask exchange S20, one TIS scan S17 can be repeated and focal plane modification can be updated. The system calibration process S19 may also be repeated between some or all exposure. The substrate table which **** the exposed wafer after termination of all exposure is exchanged in the meantime at the substrate table and the process S13 of ****(ing) a carrier beam wafer for the process S1 of drawing 9 thru/or S10. The exposed wafer is taken out so that the substrate table which **** the exposed wafer may be moved to a loading station, and it can load with a new wafer and this cycle can be resumed.
[0057] In order to explain the wafer height map creation scan of process S9 of drawing 9 , drawing 11 shows the example of the pattern of the various configurations arranged on a wafer so that silicon area may be used best, and the exposed region C of magnitude. A triangular free space is inevitably left behind to the general target which the mark attachment lane SL separates a different exposed region C, and "rat bites, and is known as blemish" between a rectangle exposed region and the curvilinear edge of a wafer. Once all production processes complete these mark attachment lanes (a different device is separated like), will just be going to cut this wafer. A certain cutting technique it is required that all the mark attachment lanes of an one direction should straddle the whole width of face of a wafer -- ******** --; -- if this equipment should be used in step - and - scan mode in that case, it is convenient to turn all these wafer width-of-face mark attachment lanes to parallel in a scanning direction (for example, the direction of Y). These mark attachment lanes and a rat may bite, and a blemish may not be exposed, then this wafer may have the height and surface characteristic to which they differ dramatically some down stream processing or covering of a layer from an exposed region C after a carrier beam. Therefore, it is important that height measurement of these fields that are due to be exposed and that are not is disregarded.
[0058] In order to measure height simultaneously at nine points (field), the linearity array of nine optical spots arranged at right angles to a scanning direction is used for the example of a level sensor suitable now. (It should be cautious of the ability to interpolate in order to give Z location data with which a substrate table corresponds by the array of the level sensor point that Z interferometer data also correspond.) The array of this spot is sufficient magnitude to cover the width of face of the **** exposed region which can be exposed with this equipment.
[0059] current -- scanning the array of a spot in the meandering path 50 so that the airly disk of this array may pass along a suitable scanning mode along with the intermediate cable of each train of an exposed

region -- it is --; -- this intermediate cable is equivalent to the intermediate cable of the slit illuminated in this exposure process. Thus, the made data can be connected an exposure scan and directly by the minimum relocation or count. Since this approach scans at both a measurement station and an exposure station by turning Z interferometer beam to a substrate table in the same location on the mounting beam mirror 31, it loses a part of degree effect of mirror complaint side. If the train of a die is narrower than the array of the spot of a level sensor, the data obtained from the spot which is not into an exposed region thoroughly will be disregarded. It may be possible to adjust in other examples of a level sensor, so that the width of face of the array of a spot may be doubled with the width of face of an exposed region.

[0060] Supposing the center line of an exposed region with a wafer has shifted in the direction more nearly vertical to a scanning direction than the remaining center lines, it may be advantageous to use a correction scanning mode. This situation is shown in drawing 12 and it shows that the center line of the die E of one line has shifted from the remaining dies D. In such a case, a map can be made from small acceleration to a substrate table by scanning two meandering paths more promptly. One path shown in drawing 12 by 52 covers 1 set of exposed regions D, and other paths shown by 53 cover other fields E. Of course, other arrays of an exposed region may require the further correction of a scanning mode.

[0061] Although it is being, when it has the linearity or the linearization range where the level sensor was restricted, the substrate table WT must be scanned by the vertical position which carries in a wafer front face within the limits of it under it. It is not so simple to find a wafer front face by the close feedback loop to the substrate table positioning system of reading of a level sensor, when a level sensor moves on an exposed region from the exterior of a wafer at the beginning, although it is easy to adjust the vertical position of the substrate table WT, in order to maintain a wafer front face at this linearity or linearization within the limits once it finds a wafer front face. There are some of such ON points, the reference figure 51 and an arrow head show on the meandering path 50 of drawing 11 , and a problem is compounded with a meandering path.

[0062] In order to find a wafer front face at the ON point 51, it is possible to prepare a prehension spot before the main level sensor spot array. Next, an echo of this prehension spot on a wafer is led to the detector which has the prehension range larger than the case of the main spot. However, this requires a limit of the scan only to the prehension spot of the both sides (before/after) of an additional hardware:main spot, or one direction. The alternative which does not necessarily require additional hardware is performing a stop and wafer prehension for a substrate table near [****] each, and measuring a wafer front face in the linearity or the linearization range of a level sensor, and approximating a wafer surface location at this ON point. However, this makes this measurement procedure quite late, and may be the result which is not desirable from the point of a throughput.

[0063] In this example of this invention, after catching a wafer front face for these problems, it avoids by performing an above-mentioned global-area level profile scan (process S5 of drawing 9). This global-area level profile scan is further explained with reference to drawing 13 .

[0064] For this global-area level profile scan, as a point with the sufficient convenience in an exposed region C to the beginning (the thing near an edge is desirable) is under a single prehension spot and the main spot of a level sensor (spot array), a substrate table is arranged. For example, by scanning a substrate table, a wafer front face is found, and a substrate table is scanned so that the central spot 41 may next cross the surrounding path 60 inside the perimeter of all exposed regions, until it catches a wafer front face and comes to linearity [of the main spot], or linearization within the limits. This prehension procedure is explained in detail below. Measurement of wafer surface height is performed in the location where the surroundings of this scan were decided. Of course, an airly disk can also perform measurement from these spots as well as this central spot, when other spots of this array hit on a wafer (exposed region). However, measurement should not be performed from the spot which hits out of an exposed region. When; which is the path which approaches considerably and follows the edge of an exposed region, and which wound, however a smoother path may also be used and the exposed region is well stuck for the wafer especially, the circular course 61 is enough as the global-area level profile path 60, and it may be convenience more, so that it may illustrate. The data of the measurement which could arrange this global-area level profile as a circle which a rat bites and passes along a blemish top, the rat bit in that case and did not perform measurement on a blemish, or the rat blew and was performed on the blemish are disregarded for the global-area height of a wafer, and count of dip.

[0065] The data collected by the global-area level profile scan are used for the two object. It is used in order that the data relevant to wafer height may predict the wafer height in the ON point 51 near [ON point 51 (refer to drawing 11)] the height map creation scan which should be performed [1st] behind, and during a

map creation scan, in order to put a wafer surface location into linearity or linearization level sensor within the limits, a substrate table is made to be made into right height. When the most, especially in order for that to need only few data points but to enable prediction of wafer height exact enough by interpolation or extrapolation moreover, it does not need to be close to an ON point. Since this level sensor has the array of a spot which needs to be made into linearity or linearization within the limits altogether (preferably) in the direction of X, it is also desirable to get to know the local Ry dip in the ON point 51 to a height map creation scan. If a global-area level profile scan is parallel to the direction of Y near [which] an ON point or close to parallel, Ry dip cannot be decided to be accuracy using the data obtained only from the single spot. When using the level sensor which has the array of a measurement spot estranged in the direction of X so that it may explain below, local Ry dip can be decided using the data from two or more spots. Of course, if a part of array comes outside an exposed region, the data from the spot in the field will be chosen.

[0066] The 2nd application of global-area level profile data is deciding a global area or an average, height, and dip (circumference of biaxial) for all wafers. This is performed by the known mathematical technique, for example, a least square method, in order to decide the flat surface which suits to collected wafer height data best. If this global-area dip (a "wedge" is sometimes called) is larger than a predetermined value, this may show enough that a charger's order is not right. In that case, it can even perform eliminating, supposing it can take out and re-load with a wafer for retry and continues failing. Using this global-area height and dip information, in order to decide the space relation to the reference marker on a substrate stage of the alignment marker on a wafer to be accuracy, the precedence alignment sensor used at the process S10 of drawing 9 is converged. This precedence alignment sensor and process are indicated in the detail at WO 98/39689 (P-0070).

[0067] During a wafer map scan, a level sensor 10 offers Continuation Z and Ry feedback signal to a substrate table, and maintains a level sensor 10 in the linearity or the linearization range. if -- this feedback loop -- stopping (a level sensor 10 not supplying the number of the rights) -- a table is controlled by following the path corresponding to a global-area wafer wedge (Z profile by the global area Rx).

[0068] The example of a level sensor 10 suitable now is shown in drawing 14 , and it explains below additionally with reference to drawing 14 A thru/or drawing 14 G which shows the mode of actuation of this sensor.

[0069] A level sensor 10 contains the detection branch 12 which depends on the vertical position on the beam generating branch 11 which turns the measurement beam bLS on Wafer W (it or other reflectors when [or] measuring the vertical position of a physical reference flat surface), and the front face of a wafer and which measures the location of the reflected beam.

[0070] In this beam generating branch, a measurement beam is generated according to the light source 111, it generates in luminescence, the array of a laser diode, or others, and that light source may be sent to "illuminator" 111 with an optical fiber. As for the beam which the light source 111 takes out, it is desirable that broadband wavelength, 600 [for example,], thru/or 1050nm are included so that the wavelength dependency of the cross protection from a wafer front face may be especially averaged after some down-stream-processing termination. You may also include some suitable combination, and the illumination-light study system 112 collects the light of a lens and a mirror which the light source 111 gives off, and illuminates the projection grid 113 to homogeneity. The projection grid 113 is shown in a detail at drawing 14 A, and in order to make the separate spot of /each, it consists of opening 113b of the addition which makes a prehension spot before these main detection spot arrays on long and slender grid 113a which you may divide into the shaft by carrying out a gridline at parallel, and a wafer. The period of this grid may be decided in part with the precision which should measure this wafer surface location, for example, about 30 micrometers of it are sufficient. Also to which axis of coordinates, to the circumference of that optical axis, it rotates slightly, and the gridline projected on a wafer arranges this projection grid, and avoids interference with the structure on the wafer which meets in x or the direction of y by it so that in parallel. The projection lens 114 is telecentric system which projects the image of the projection grid 113 on Wafer W. the projection lens 114 makes chromatic aberration of the projected image min, or avoids it -- as -- essential -- a reflected light study component -- or -- so much -- since -- changing -- desirable --; -- a projection beam is a broadband and that is because they cannot be easily removed or compensated with dioptric system. The projection beam bLS is taken in and out of the projection lens 114 using mirrors 115 and 116 by return, and arrangement with sufficient convenience of the components of this beam generating branch is enabled.

[0071] As opposed to a normal, incidence of the projection beam bLS is carried out to a wafer at an angle of [quite big / alpha] the range of 60 degrees thru/or 80 degrees, and it is reflected in the detection branch 12. If the location on the front face WS of a wafer moves only distance deltah to location WS' as shown in

drawing 14 B, only distance 2 and delta h-sin (alpha) move reflective beam r' to the beam r before migration of a wafer front face. By drawing 14 B showing the appearance of the image on a wafer front face, since; incident angle is large, this image spreads at right angles to a gridline.

[0072] Reflective beams are collected according to the detection optical system 121, and it converges on the detection grid 126, and that grid is the duplicate of the projection grid 113 intrinsically, and it is subdivided so that it may correspond to this spot-array pattern. The detection optical system 121 is a projection optical system 114 and the direct complementation, and in order to make chromatic aberration into min, it consists only of a reflected light study component or it intrinsically. Convenience may improve arrangement of components using mirrors 122 and 123 by return again. The birefringence crystal 125 which makes a gap vertical to a gridline in magnitude equal to the horizontal of this light and the grid period between vertical polarization components is located in the linearity polarizer 124 and list which polarize light at 45 degrees between the detection optical system 121 and the detection grid 126. the beam in the detection grid 126 in case drawing 14 C does not have this birefringence crystal -- being shown --; -- they are a series of light band regions and dark band regions which carry out alternation, and 45 degrees of light band regions polarize. The birefringence crystal 125 changes a horizontal and a vertical polarization condition so that the light band region of a level polarization component may fill the dark band region of a vertical polarization component. Therefore, as shown in drawing 14 D, although the illuminance in the detection grid 126 is uniform gray, it has the strip of the polarization condition which carries out alternation. When drawing 14 E shows the detection grid 126 which depends on the vertical position on the front face of a wafer and which was put on this pattern and; wafer is in a nominal zero vertical position, the detection grid 126 carries out the bonnet lock out of the one half of one polarization condition, for example, a vertical light band region, and the one half of other conditions.

[0073] The light which passed the detection grid 126 is collected according to the modulation optical system 127, and it converges on a detector 128. Modulation optical system contains the polarization modulation equipment driven with an alternation signal with a frequency of about 50kHz so that it may let two polarization conditions pass by turns. Therefore, the image which a detector 128 looks at carries out the alternation of between two conditions shown in drawing 14 F. A detector 128 is divided into the field of a large number corresponding to the array of the spot which should measure height. The output of a field with a detector 128 is shown in drawing 14 G. It is an alternation signal with a period equal to it of modulation optical system, and the amplitude of this oscillation shows alignment extent of the reflected image of the projection grid to a detection grid top, therefore the vertical position on the front face of a wafer. As mentioned above, if a wafer front face is located in a nominal zero location, the detection grid 126 will have the equal reinforcement which intercepted the one half of a vertical polarization condition, and the one half of a level polarization condition, then was measured, and the amplitude of the vibrating signal output by the detector field will be zero. If the vertical position on the front face of a wafer moves from this zero location, the detection grid 126 will begin to prevent many of through and vertical polarization bands for many of level polarization bands. Then, the amplitude of an oscillation will increase. The amplitude of this oscillation which is the scale of the vertical position on the front face of a wafer is not related to a direct radiation form by NANOMETA at the vertical position on the front face of a wafer. However, it can decide easily by initialization (and if , recalibration was carried out periodically) of this equipment by measuring the fixed height of the front face of a naked silicon wafer by the vertical position from which the versatility of a substrate table differs using Z interferometer which proofread the amendment table or the formula, and the non-proofread level sensor 10.

[0074] A synchronous bus is formed in order to guarantee having performed measurement of a level sensor and Z interferometer simultaneously. This synchronous bus tells the clock signal of the very stable frequency which the master clock of this equipment generated. Both a level sensor and Z interferometer are connected to this synchronous bus, and the sampling point of those detectors is decided using the clock signal from this bus.

[0075] Prehension spot 113b which passed the projection grid 113 passes along a detection grid, as it shows drawing 15 A there, two 131 and 133 are set up highly and incidence of one 132 is carried out to three different detection fields set up low. The output from this low detection field is lengthened from the High Public Prosecutors Office appearance field to an output. When a wafer front face is located in a zero location, these prehension spot detector fields are arranged so that the output which the prehension spot hit high and a low detection field equally, and lengthened to it may be zero. When it separates from a zero location, the increase of the magnitude of the output which more prehension spots to one of the detection fields than others hit, and lengthened, and its sign show whether a wafer is too expensive or it is too low.

The dependency to the substrate table location ZIF of the lengthened detector output dcap is shown in drawing 15. This form of a detector output makes possible the zero prehension approach quicker than the conventional servo feedback. According to this approach of having improved called "move-until", when a prehension spot detector shows past [on the front face of a wafer / the high one] or past [the low one], Z location actuator of a substrate table directs to move this stage in the suitable direction, in order to put this wafer front face into linearity [of the main level sensor array], or linearization within the limits. Motion of this wafer stage continues until the output of a prehension spot detector passes the trigger level th or tl, and according to that direction, it moves it. If trigger level is crossed, the control device of this equipment will be made to come out of an instruction to Z location actuator, and a brake procedure will be begun. Such trigger level is set up so that this stage may move to a zero location or may approach into the time amount required in order to apply brakes to this response time and stage motion. Then, this stage can be brought to a zero location under control of the more exact main level sensor spot. It is not necessary to decide these trigger points according to the dynamics of this stage, and to estrange them to the symmetry around a zero detector output. Without requiring a linearity gaging system, the this "move-until" control system enables quick and strong zero prehension, and can use it for other situations.
[0076] The level sensor explained above can be further optimized, in order to improve the engine performance. An improvement of the precision of the scan (Y) direction can be made by suitable signal filtering, and this may be fitted to the specific process layer seen on the wafer processed selectively. The improvement (as opposed to a specific process layer) of an addition of all the directions may be obtained changing the projection grid 113 or by adjusting a detection system (the magnitude, location, and/or angle of a detector resolution a list the number of detectors) by changing the illumination-light study system 112 (in order adjusting the homogeneity of the illumination light on the projection grid 113, and/or angular distribution).
[0077] The form of the reliance sensors 20a and 20b suitable now is shown in drawing 16 and drawing 17 . The beam generating branch 21 includes the light source 211 (for example, a solid-state laser diode or super luminescent diode) which gives off the light of the limited bandwidth. It is convenient for it to be separated and located from a measurement frame and to bring the output to a desired point with an optical fiber 212. This light is outputted from the fiber termination machine 213, and it turns on a beam splitter 215 according to the collimator optical system 214. Beam splitters 215 are two parallel measurement beams [outside 1].
$b_{c\theta 1}$および$b_{c\theta 2}$

In order to illuminate each spot 23 on Wafer W for structure and them to homogeneity, it converges according to the tele cent rucksack projection optical system 216. Since the bandwidth of the measurement beam of this reliance sensor is restricted, a refractility component can be used for a projection optical system 216 with sufficient convenience. The beams by which the detection optical system 221 was reflected are collected, and it converges on the edge of the detection prism 222 located between detectors 223 and 224 and the detection optical system 221 in them. As shown in drawing 17 which is the side elevation of the detection prism 222 and a detector 223, incidence of the measurement beam is carried out to the tooth back of the detection prism 222, and it comes out from inclined planes 222a and 222b to it. The detector 223 is arranged so that it may consist of two detector components 223a and 223b, the light which comes out of field 222a of the detection prism 222 may reach detector component 223a and the light which comes out of field 222b may reach detector component 223b. The detector 224 is the same. The output of the detector components 223a and 223b is evaluated and subtracted by reinforcement. When a wafer front face is located in a zero location, these measurement beams turn a hit and an equivalent light to the detector components 223a and 223b on field 222a of the detection prism 222, and 222b at the symmetry. Next, the output which these produced the equivalent output, then was subtracted becomes zero. If a wafer front face moves from this zero location, the location of the reflected beam will change proportionally the output which hit more mostly [one of taking up and down and the fields 222a and 222b] than others, and resulted in turning much light by each detector component, then was subtracted. The dip of a wafer can be decided by the comparison of the output of detectors 223 and 224.
[0078] This arrangement is the 2nd example of this invention, and brings about easy and strong the height and level detector which can be used for a list as a check sensor for other applications. this check sensor -- mainly -- measurement and initialization of Z interferometer of an exposure station -- and periodical, for example, a moon unit, recalibration is meant. However, the check sensor explained above has the prehension range larger than TIS used for the precise decision of the location of the focal plane of the projection lens PL to the substrate table WT, and a quick response. Therefore, when exchanging a substrate

table to an exposure station first, check check sensor 20a can be advantageously used, in order to make the coarse decision of the vertical position of TIS. It connects with the best focal adjustment location which measured previously the height measured by this check sensor, and it uses in order to predict the starting point and range for the TIS scan near the location which this best focal plane expects. This can make short, therefore quick the TIS scan explained above, and means improving a throughput.
[0079] The beam splitter 215 which can be used for these check sensors is shown in drawing 18 . A beam splitter consists of many prism of equal thickness desirable from the same glass. The basic principle of operation is explained using the beam splitter which consists of three prism 51, 52, and 53. A cross section is a trapezoid and the input beam 54 carries out incidence of the prism 51 near one side of the top face 55. As for the location of the input beam 54, it hits this top face 55 and one side face 56 of the 1st 45-degree prism 51. The 2nd prism 52 is joined by the side face 56 of the 1st prism 51, the part (this example one half) of a request of this input beam carries out Naoiri into the 2nd prism 52, a beam 57 is formed, and on the other hand, the remainder applies this joint so that it may reflect horizontally within the 1st prism 51 and a beam 58 may be formed. In the 2nd side face 59 parallel to the 1st side face 56 of the prism, it is reflected caudad, and the beam 58 reflected by the 1st prism 51 comes out of the underside of the 1st prism 51, and passes along the top face and base of the 3rd prism 53 parallel to the top face of the 1st prism 51. The 2nd side face 59 may be applied if needed, in order to guarantee all the internal reflection of a beam 58. Internal reflection of the beam 57 included in the 2nd prism 52 is carried out by two parallel sides of the 2nd prism 52 vertical to the side face 56 of the 1st prism 51, and it comes out from the top face 55 of the 1st prism 51, and the parallel base of the 2nd prism 52. It separates and beams 57 and 58 are outputted by it, although it is parallel. The separation between a beam 57 and 58 is decided by magnitude of prism 51 and 52. Prism 53 is formed in order to equate the optical path length of both beams so that a beam 57 and image formation optical system for 58 can be made the same. Although prism 53 also supports prism 52 like a graphic display, with a certain application, it may be [prism] unnecessary in this. In order to improve an echo of the beam 57 in the field where prism 52 and 53 touches, it may leave an opening or a suitable coat may be prepared.
[0080] A beam splitter 50 is easy, strong, and easy to make. It brings about an output beam with the equal optical path length by parallel (as opposed to the conventional cube beam splitter bringing about a straight beam). this parting plane -- a polarization case index -- or it can do not right [that] and, in the case of the latter, a request can divide input beam reinforcement uniformly or unequally.
[0081] It is the description of other optical height sensors that it is insensible in the dip of the wafer stage of the circumference of a shaft vertical to the Z direction defined by the crossover of the wafer front face WS and the focal plane of the measurement spot of a level sensor 10 at the level and the reliance sensor which were explained above, and a list. This is based on the data that these sensors cover the field of the measurement spot which even the focus shaft of a spot extrapolated, and measure height. This dip insensible nature can be used in order to proofread Z interferometer and a photosensor to the more nearly mutual one at XY flat surface. A similar procedure can be used for a check sensor or the photosensor of other resemblances although the procedure for such a configuration is explained with reference to drawing 19 and a level sensor.
[0082] It can set up so that a revolution may be added to the surroundings of the shaft with which XY flat surface chose the positioning system of a substrate table using Z actuator which combined with the multiaxial interferometer systems this Z interferometer of whose is that part, and was estranged. In order to align this Z interferometer measuring point with a level sensor measurement spot, this Z interferometric measurement location is rotated for this stage using this positioning system to the circumference of a passage, for example, a shaft parallel to a Y-axis. Z location of this table measured with Z interferometer does not continue not changing during this dip. If a level sensor and Z interferometer are aligned at accuracy, a wafer surface location will not continue not changing, either. However, as shown in drawing 19 , only amount delta X has shifted from Z interferometer location, and if a level sensor measuring point inclines toward the location which shows the substrate table WT by the imaginary line in the drawing, it will produce change deltaWLS in a level sensor output. Therefore, location gap deltaY of location gap deltaX and the direction of Y can be promptly decided by detecting change of the level sensor output by the dip of the circumference of two desirable vertical shafts which pass through Z interferometer location. Then, the parameter of these interferometer systems or a level sensor 10 can be adjusted so that it may guarantee that this interferometer measuring point counters a level sensor measuring point and accuracy.
[0083] When a level sensor uses the array of a measurement spot, it always should not be guaranteed that these spots have aligned at accuracy. Therefore, it can opt for a location gap of each spot from the nominal

location about Z interferometer location using the above-mentioned technique. Next, a height map or a level sensor output can be amended using this information.
[0084]
[Example 3] The 3rd example is the same as the example except for using the leveling principle of the 1st example, then explaining below. The hardware of the 2nd example and amelioration which were explained above may also be used for this 3rd example. However, the approach improved for optimization of an exposure path is used for this 3rd example. This is explained with reference to drawing 20 below.
[0085] Although a substrate stage is immobilization and what is moved actually is a wafer as argued above, it is well appropriate to convenience to think that an exposure slit image moves. The following explanation is given from this viewpoint.
[0086] Drawing 20 shows the notation used below. Although slit image SI is separated from a wafer front face and drawn by drawing 20 for plainness, the focal plane of a slit image should notice the object of this optimization procedure about it being guaranteeing it being in agreement with a wafer front face as much as possible during exposure. : which can calculate the moving-average (passage of time) focal gap MA corresponding to the coordinate on this wafer (y) as follows if a front face considers the 1-dimensional wafer and slit image SI which are defined by w (y) -- [Equation 2]

$$MA(y)=\frac{1}{s}\int_{-\frac{s}{2}}^{\frac{s}{2}}[w(y)-[z(y+v)-vRx(y+v)]]dv \qquad (2)$$

However, this integral is performed by covering the slit size s of a scanning direction, and integrand w(y)-[z (y+v)-vRx(y+v)] is a focusing error on the point of the wafer of a certain flash. migration standard deviation [as opposed to / similarly / the point on a wafer] -- as follows -- a definition can be given -- : -- [Equation 3]

$$MSD^2(y)=\frac{1}{s}\int_{-\frac{s}{2}}^{\frac{s}{2}}[w(y)-[z(y+v)-vRx(y+v)]-MA(y)]^2dv \qquad (3)$$

It is the focal gap time variation under actual exposure of the point on a wafer. : defined as follows using a secondary focal gap term in order to make the flat surface of an exposure slit image, and the difference between wafers into min -- [Equation 4]

$$MF^2(y)=\frac{1}{s}\int_{-\frac{s}{2}}^{\frac{s}{2}}(w(y)-[z(y+v)-vRx(y+v)])^2dv \qquad (4)$$

MF (y) is called a migration focus here. : which can write MF (y) also as follows by the term of MA (y) and MSD (y) -- [Equation 5]

$$MF^2(y)=MA^2(y)+MSD^2(y) \qquad (5)$$

[0087] This is optimization of an exposure path, and the minimization of a migration focus covering an exposed region, and, unlike simple least square method optimization of the 1st example which disregards time amount, therefore a scan integral, means taking both the moving average and migration standard deviation into consideration. A formula (3) and (4) apply Ry (t) dependency, and it can extend to two-dimensional easily by integrating with MF about X from -W/2 to +W/2, however W is the width of face of the slit of the direction of X. In order to calculate this optimization, it is convenient to use a frequency-domain expression. With some or all degrees of freedom, count in a frequency domain filters the RF fluctuation of a set point which will bring a result which produces superfluous substrate stage acceleration, and also removes it so that an exposure path may be optimized to the engine performance of a substrate table positioning system.
[0088] although it assumed that the optimal focus of an exposure slit image was in agreement with a flat surface in the upper argument --; -- this -- not necessarily -- that is not right --; -- in practice, the optimal focus may be in the field of arbitration and may produce the so-called focal plane deflection (FPD). In order to make the focal map f (x y), supposing it is able to measure or calculate the profile of the field on an exposure slit field using TIS, the made data or the formula can be added to the upper formula so that wafer

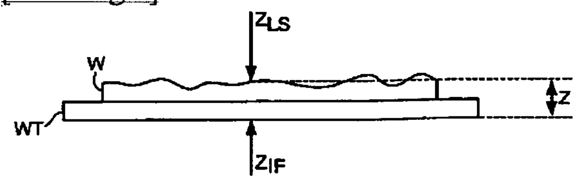
motion may be optimized to the actual optimal upper ****.
[0089] It can finish [rather than] with good focusing and a smoother substrate stage path to a scan system, and the optimization technique of this 3rd example increases a throughput and a yield.
[0090]
[Example 4] In the 4th example, it has the additional description for negating the error which may be produced by interference between the beams in which the level sensor was refracted into the beam reflected by the top face of a resist layer, and the resist layer, and was reflected by the base by measurement of a wafer surface location. Otherwise, this 4th example may be the same as any of the 1st explained above thru/or the 3rd example they are.
[0091] Of course, interference of the beam reflected from the above-mentioned top face and the base depends for the optical wavelength and the angle of incidence of a measurement beam on a resist property and a wafer surface characteristic greatly. In order that the broadband light source and a detector may average such single wavelength interference, it is used now. If it measures by the approach which carried out spectral decomposition of the wafer surface location and it performs separate measurement to much wavelength of a broadband measurement beam, an improvement of this equalization principle is realizable. In order to attain this, it is required to make the wavelength (color) system divided into measurement of a wafer surface location in time or spatially. This needs the following modification for the measurement principle of a level sensor.
[0092] The 1st possible modification to a level sensor is being able to generate selectively and replacing the light beam of wavelength range (color) which is different in the continuation broadband light source. This can be attained by using some independently selectable light sources using the light source which can adjust wavelength, or by using the beam part chosen from revolution/oscillating prism in a small broadband beam by making a light filter (for example, on a carousel) which is different at the suitable point of the lighting system of a level sensor intervene selectively. Next, the light of the wavelength from which a measurement beam differs is used using this level sensor, and some measurement on the front face of a wafer is performed on each point.
[0093] Another selection is being able to detect selectively the light of wavelength range (color) which is different in a broadband detector, and replacing it. This can be attained by dividing a measurement beam into different wavelength spatially using prism, and detecting the beam of this different wavelength with a separate detector, or the approach of others which analyze a broadband reflective beam by the spectrum in order to measure a wafer surface location by arranging a light filter to the detection optical system in front of a detector.
[0094] It is also possible for combination approach to be used and for it to be made to carry out spectral decomposition of both a projection system and the detection system by it naturally.
[0095] If there is no cross protection and the result which should come out of and carry out the result with each same measurement (as opposed to each wavelength), and is different by;, therefore such measurement will be obtained, this shows existence of effectiveness which was touched in the paragraph of the upper beginning. Then, the improved wafer surface location measurement can be drawn using various technique. For example, a consistent result may be amended or canceled. The technique of majority vote may also be used. Instead, based on the spectrometry of a wafer surface location, a actual location is guided with the model which describes the spectral response of a resist and a wafer surface characteristic, and skill is good.
[0096] Since the described cross protection depends also on the incident angle of the measurement beam on a wafer front face, it may want to evaluate this effectiveness, and to also change this incident angle so that it may subsequently be amended. Therefore, the further possible modification to a level sensor is enabling it to perform it using a measurement beam by the angle of incidence from which a wafer surface location differs. Although one method of attaining this is the same spot on a wafer, it is forming the multiplex measurement beam which has a different angle of incidence to separate projection and detection optical system. Instead, optical system is changeable so that the same projection and the same detection system may include a different optical axis related to various measurement beams. Another selection which makes the angle of incidence changed in time is using revolution/advancing-side-by-side cuff mirror (or other moving parts) for the optical system of a level sensor.
[0097] If there is no cross protection, the result with the same measurement by different incident angle should be come out of and made to be the same as that of the wavelength dependency explained above. Therefore, if there is conflict (fluctuation by the angle of incidence), it avoids and compensates or a model can be made by the same approach.
[0098] Of course, the above-mentioned additional description and an improvement may be independently

used for the photo sensor except having explained here together.
[0099]
[Example 5] The 5th example of this invention is shown in drawing 21 . The 5th example of this invention is 9 thru/or the extreme ultraviolet rays (EUV) of the wavelength of the range of 16nm, and lithography equipment that uses reflexibility mask MA' as an exposure radiation. At least, although the components of this 5th example are generally the same as the thing of the 1st example functionally, it is made for them to suit the exposure radiation wavelength to be used, and those arrangement is adjusted so that it may be adapted for the beam path needed by the activity of a reflexibility mask. optimizing lighting and projection optical system IL', and PL' at the wavelength of an exposure radiation in special adaptation which may be the need -- it is --; -- this is accompanied by generally using the optical element of the reflexibility instead of refractility. The example of illumination-light study system IL' used for an EUV radiation is indicated by the European Patent application 00300784th and No. 6 (P-0129).
[0100] The important difference between the lithography equipment using a reflexibility mask and the thing using a penetrable mask is that the degree of complaint side of a mask becomes the position error on a wafer which increases according to down-stream optical system, i.e., the optical path length of projection lens PL', with a reflexibility mask. This is because the height and/or slope deviation of a mask change locally the effective incident angle of the lighting beam on a mask, therefore XY location of the image gestalt on a wafer is changed.
[0101] According to the 5th example of this invention, the effect of the degree of complaint side of a mask makes the height map of a mask in advance of exposure, and is avoided or mitigated by controlling at least one mask location of Z, Rx, and Ry during exposure. Although this height map can be made by the approach (namely, off axis leveling of the mask in a measurement station) of having explained above and resemblance,;, however it are made from the mask of an exposure station, and it may abolish the need of relating a height map with a physical reference side. Although count of the optimal location of the mask under exposure or exposure scan (exposure path) may be equivalent to having explained above, it may combine it with optimization of a wafer and a mask exposure path. However, it may be more advantageous to put weight on the optimization count, since slope deviation has big effect in the location in a wafer to a mask.
[0102] The lithography projection equipment by this invention should also note clearly that two substrate tables (above) and/or two mask tables (above) may be included. In such a scenario, the 1st substrate on the 1st substrate table receives height map creation at a measurement station, and it is able to be for the 2nd substrate on the 2nd substrate table to receive exposure simultaneously at an exposure station, and the same on the other hand, in the case of; and two or more masks table. Such a configuration can enlarge a throughput dramatically.
[0103] This invention should note clearly that only substrate leveling is also applicable to the combination of mask leveling or substrate leveling, and mask leveling.
[0104] Although the specific example of this invention was explained above, probably, it turns out that you may carry out by having explained this invention and the option. It does not mean that this explanation limits this invention.

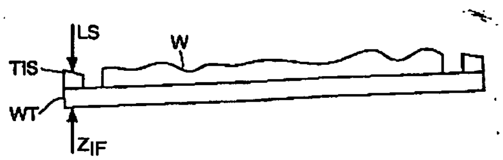
[Translation done.]

DRAWINGS

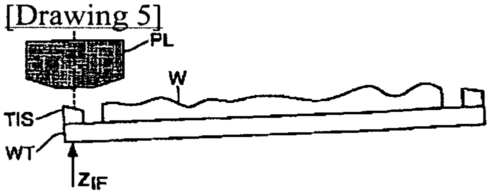
[Drawing 2]



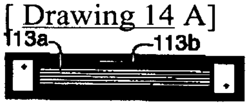
[Drawing 3]



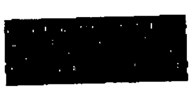
[Drawing 5]



[Drawing 14 A]



[Drawing 14 D]



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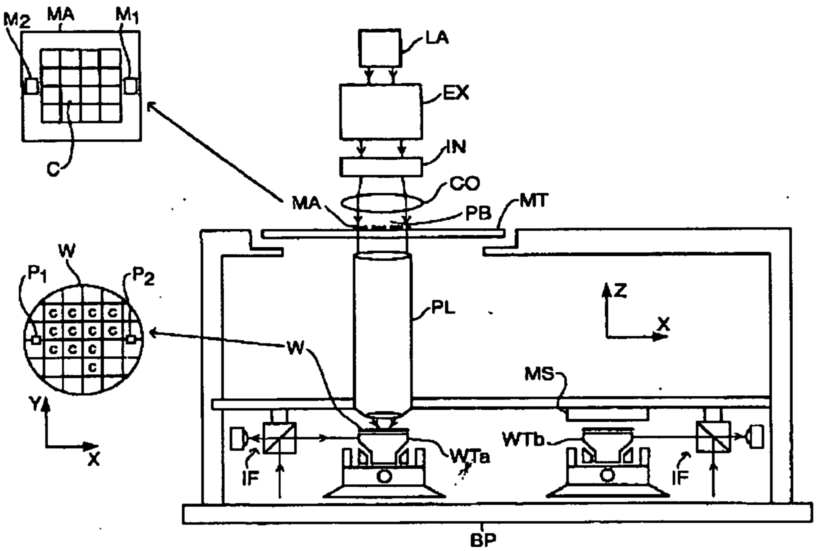
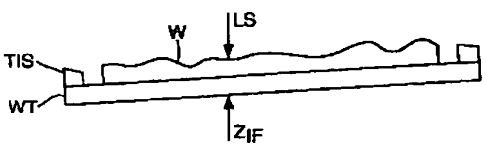
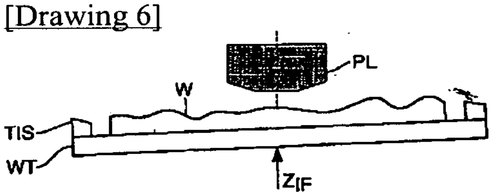


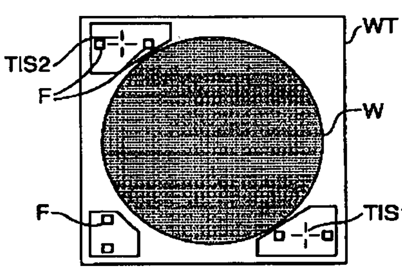
[Drawing 4]



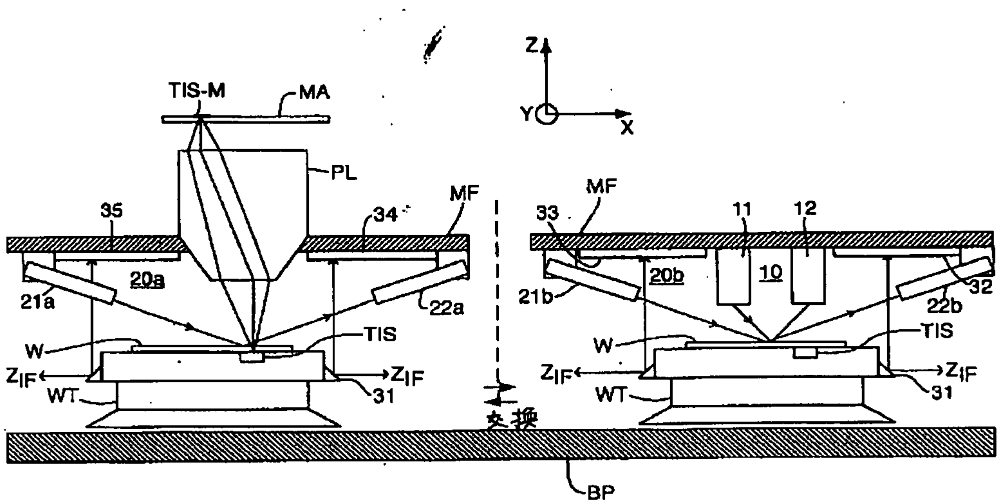
[Drawing 6]



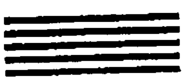
[Drawing 7]



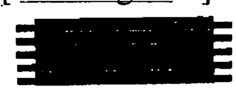
[Drawing 8]



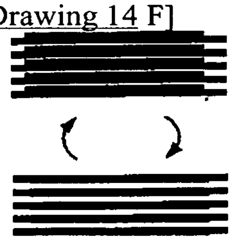
[Drawing 14 C]



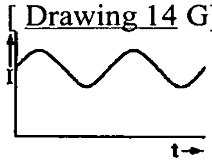
[Drawing 14 E]



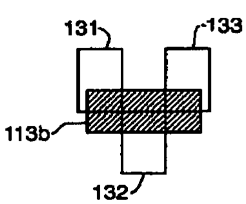
[Drawing 14 F]



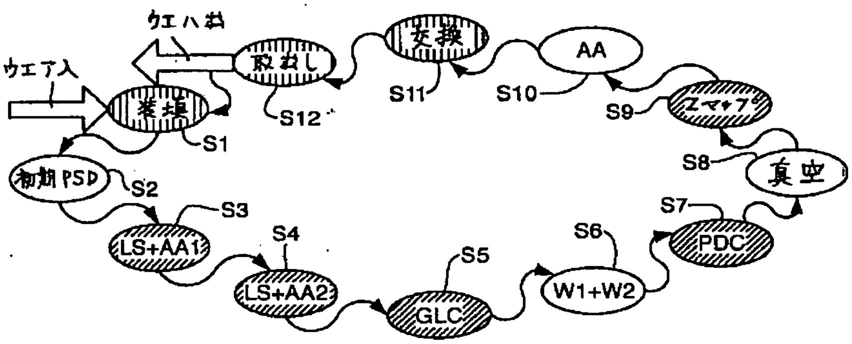
[Drawing 14 G]



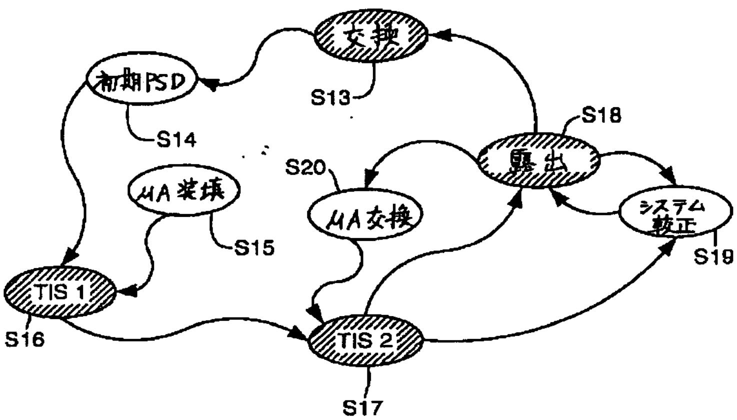
[Drawing 15 A]



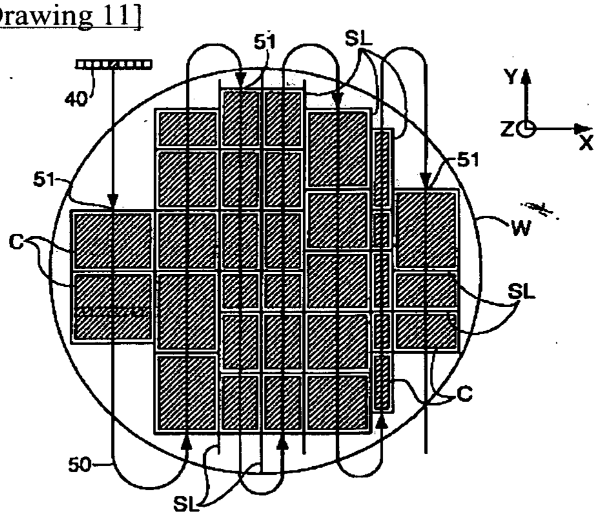
[Drawing 9]



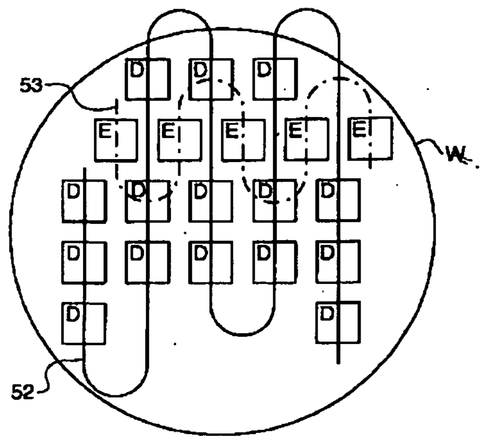
[Drawing 10]



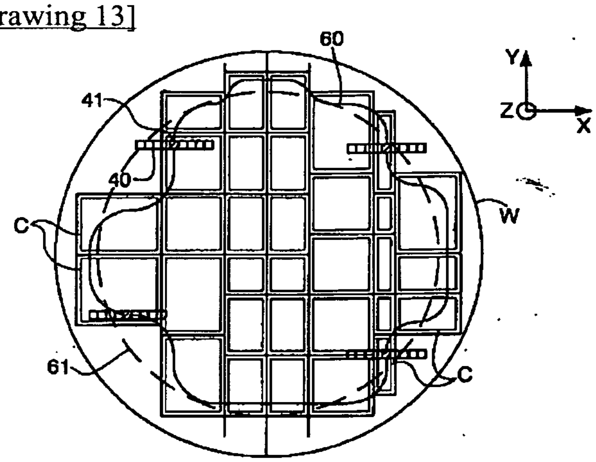
[Drawing 11]



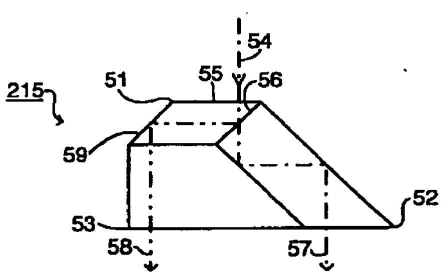
[Drawing 12]



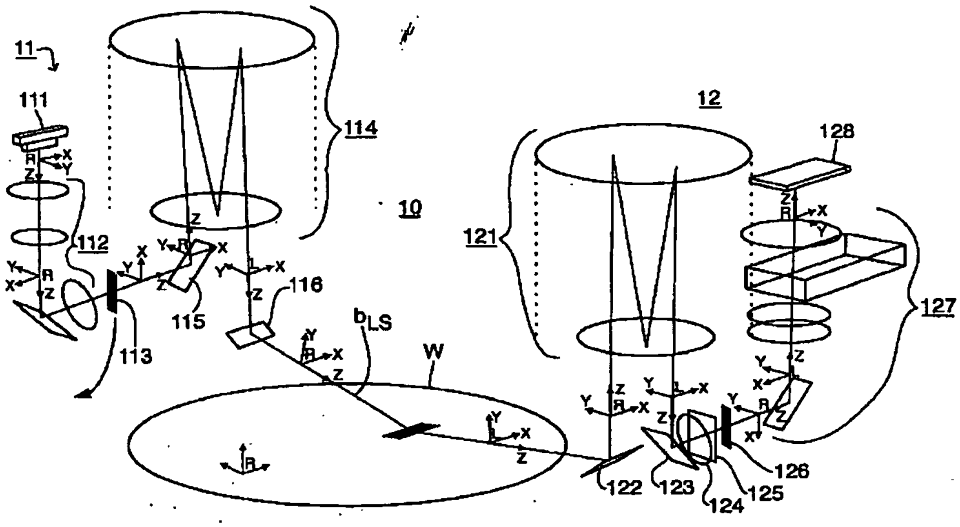
[Drawing 13]



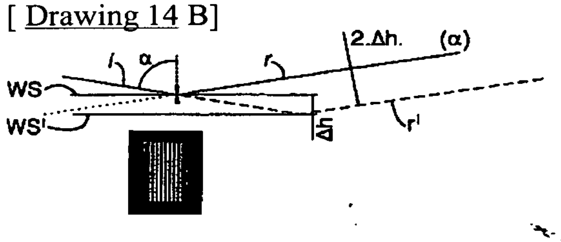
[Drawing 18]



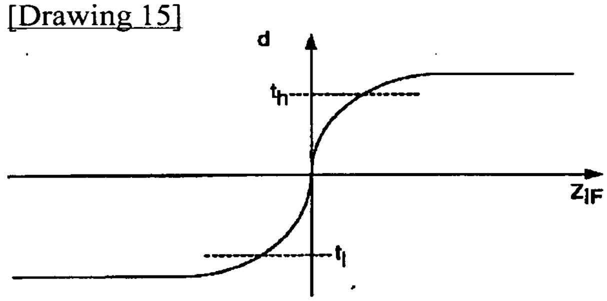
[Drawing 14]



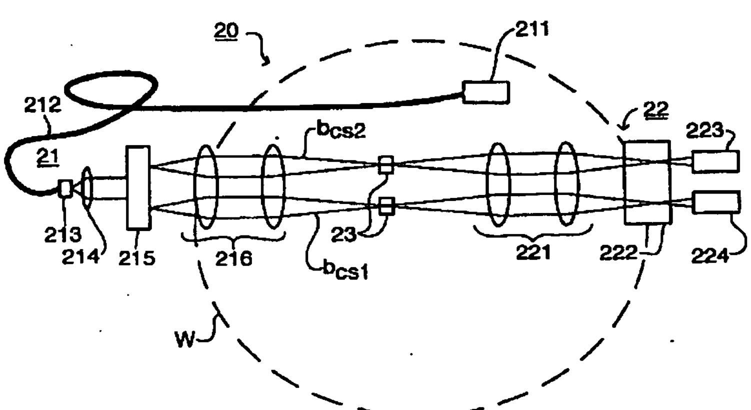
[Drawing 14 B]



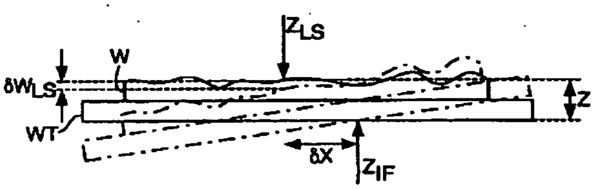
[Drawing 15]



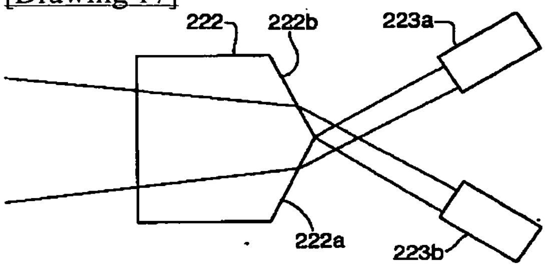
[Drawing 16]



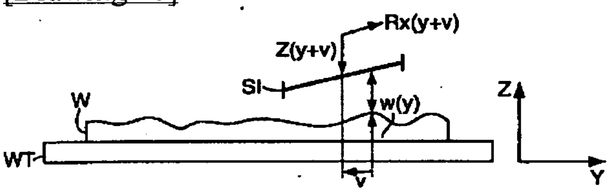
[Drawing 19]



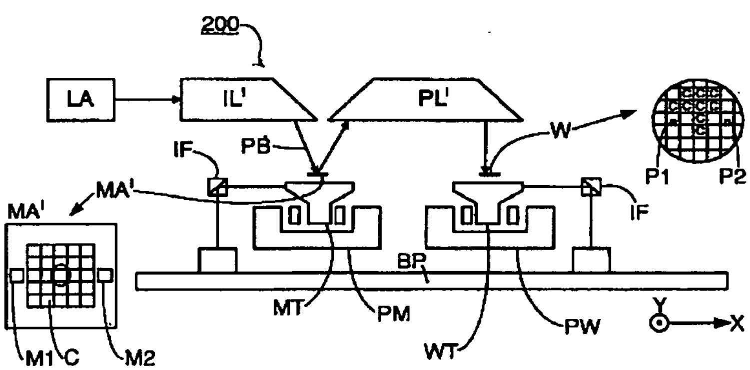
[Drawing 17]



[Drawing 20]



[Drawing 21]



[Translation done.]

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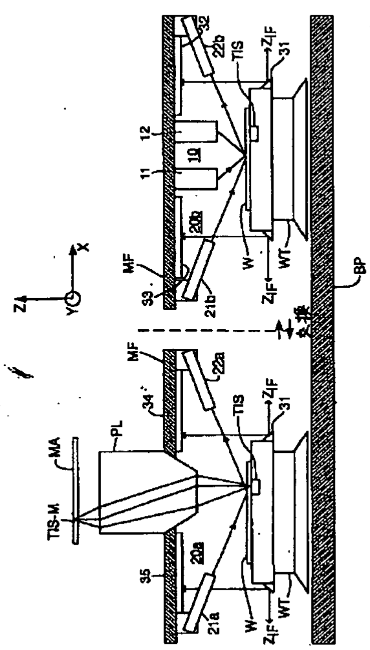
最終頁に続く

(54)【発明の名称】　リソグラフィック投影装置のオフアキシレベリング

(57)【要約】

【課題】　複数の基板テーブルまたはマスクテーブルがあるリソグラフィ投影装置に於いて、複数のステーションでこの基板またはマスクの高さを測定する装置間の原点を関係付ける必要をなくすること。

【解決手段】　基板Ｗを基板テーブルＷＴに装填してから、測定ステーション（図８の右）で、レベルセンサ１０を使って、物理的参照面の垂直位置および基板表面の垂直位置Z_{LS}を複数の点で測定し、並びにＺ干渉計Z_{IF}を使ってこの基板テーブルの垂直位置Z_{IF}を同じ点で同時に測定し、基板表面高さ、$Z_{Wafer}=Z_{LS}+Z_{IF}$をマップにする。次に、この基板を坦持する基板テーブルを露出ステーション（図８の左）へ移し、物理的参照面の垂直位置を再び決定する。次に露出プロセス中に基板を正しい垂直位置に位置決めする際にこの高さマップを参照する。このプロセスは、マスクにも適用可能である。



【特許請求の範囲】

【請求項１】　リソグラフィ投影装置であって：放射線の投影ビーム（ＰＢ）を供給するための放射線システム（ＬＡ、Ｅｘ、ＩＮ、ＣＯ）；マスク（MA）を保持するためのマスクホルダを備える第１物体テーブル（ＭＴ）；基板（W）を保持するための基板ホルダを備える、第２の、可動物体テーブル（WT）；このマスクの被照射部分をこの基板の目標部分（C）上に結像するための投影システム（ＰＬ）；および上記第２物体テーブルを、上記投影システムが上記マスク部分を上記基板上に結像に出来る露出ステーションと測定ステーションの間で動かすための位置決めシステム；を含む投影装置に於いて；上記第２物体テーブルがそれに固定された物理的参照面を有し、

さらに投影装置が、

上記測定ステーションに位置し、上記基板ホルダ上に保持された基板（W）の表面上の複数の点の、上記物理的参照面に関する、高さを測定しおよびその高さマップを作るように構成および配設された高さマップ作成手段；上記露出ステーションに位置し、上記第２物体テーブルを上記露出ステーションへ動かしてから、上記物理的参照面の上記基板表面に実質的に垂直な第１方向に於ける位置を測定するための位置測定手段；並びに上記目標部分の露出中に、上記高さマップおよび上記位置測定手段によって測定した上記位置に従って、少なくとも上記第１方向に於ける上記第２物体テーブルの位置を制御するように構成および配設された制御手段；を有することを特徴とする装置。

【請求項２】　請求項１による装置に於いて、上記制御手段が、更に、上記高さマップに従って上記第２物体テーブルの少なくとも上記第１方向に垂直な一つの軸の周りの傾きを制御するように設けられている装置。

【請求項３】　請求項１または請求項２による装置に於いて、上記高さマップ作成手段が点の線形アレーの上記第１方向に於ける位置を測定するように構成および配設されたレベルセンサを含む装置。

【請求項４】　請求項１、請求項２または請求項３による装置に於いて、上記高さマップ作成手段が、上記第１方向に於ける位置を測定すべき表面によって反射された測定ビームの位置を測定するように構成および配設されたレベルセンサ（１０）を含む装置。

【請求項５】　請求項４による装置に於いて、上記レベルセンサ（１０）が：投影格子（１１３）；上記投影格子の像を、上記第１方向に於ける位置を測定すべき表面上に投影するための投影光学系（１１４）；検出格子（１２６）、上記検出格子上に上記投影格子の像を作るために上記表面によって反射された光を集束するための検出光学系（１２１）；および上記投影格子の上記像が上記検出格子に重なることによって出来たモアレ図形を検出するための検出器（１２８）を含む装置。

【請求項６】　請求項５による装置に於いて、上記レベルセンサが、更に、上記投影格子を多色放射線で照明するように構成および配設された放射線源（１１１）を含み、並びに上記投影光学系および上記検出光学系が本質的に反射性光学素子から成る装置。

【請求項７】　請求項１ないし請求項６の何れか一つによる装置に於いて、上記高さマップ作成手段が、上記基板の表面の上記第１方向に於ける位置を上記複数の点で検出するためのレベルセンサ（１０）、上記レベルセンサによる測定と同時に上記第２物体テーブルの上記第１方向に於ける位置を検出するための位置検出手段（ＩＦ）を含む装置。

【請求項８】　請求項７による装置に於いて、上記位置検出手段が干渉計を含む装置。

【請求項９】　請求項１ないし請求項８の何れか一つによる装置に於いて、上記位置測定手段が上記第２物体テーブルに取付けられたイメージセンサを含み、上記物理的参照面が上記イメージセンサの上面を含む装置。

【請求項１０】　請求項１ないし請求項９の何れか一つによる装置に於いて、上記位置測定手段が上記物理的参照面の、上記投影システムの焦点面に関する位置を測定するように構成および配設された装置。

【請求項１１】　請求項１ないし請求項１０の何れか一つによる装置に於いて、上記第２物体テーブルが複数の離間した物理的参照面を有し、上記高さマップ作成手段が上記複数の点の、上記複数の物理的参照面によって形成される参照平面に関する高さを測定するように構成および配設された装置。

【請求項１２】　請求項１ないし請求項１１の何れか一つによる装置であって、更に：上記露出ステーションに位置し、上記基板ホルダ上に保持された基板の表面上の上記複数の点の、上記物理的参照面に関する、高さを測定しおよびその高さマップを作るように構成および配設された第２高さマップ作成手段；および上記測定および露出ステーションに設けられた別々の位置検出システムのための相対較正を導き出すために、上記第１および第２高さマップ作成手段の各々によって用意された単一基板の高さマップを比較するように構成および配設された較正手段；を含む装置。

【請求項１３】　以下の構成を有するリソグラフィ投影装置を用いてデバイスを製造する方法であって：放射線の投影ビーム（ＰＢ）を供給するための放射線システム（ＬＡ、Ｅｘ、ＩＮ、ＣＯ）；マスク（MA）を保持するためのマスクホルダを備える第１物体テーブル（ＭＴ）；基板（W）を保持するための基板ホルダを備える、第２の、可動物体テーブル（WT）；およびこのマスクの被照射部分をこの基板の目標部分（C）上に結像するための投影システム（ＰＬ）、

上記第１物体テーブルにパターンを坦持するマスク（ＭＡ）を設ける工程；上記第２物体テーブルに放射線感応

層を有する基板（W）を設ける工程；およびこのマスクの上記被照射部分をこの基板の上記目標部分上に結像する工程；を含む方法に於いて：上記結像工程の前で、測定ステーションにある該第２物体テーブルにより、この基板表面上の複数の点の、上記第２物体テーブル上の物理的参照面に関する、高さを示す高さマップを作る工程；この第２物体テーブルを上記露出ステーションへ動かし、上記物理的参照面の上記基板表面に実質的に垂直な第１方向に於ける位置を測定する工程；並びに上記結像工程中に、この第２物体テーブルを、上記高さマップおよび上記物理的参照面の上記第１方向に測定した上記位置を参照して、少なくとも上記第１方向に位置決めする工程；とを有することを特徴とする方法。

【請求項１４】　請求項１３による方法に於いて、上記結像工程中に、上記高さマップを参照することによって、上記第２物体テーブルを少なくとも上記第１方向に垂直な一つの軸の周りに方向付けする方法。

【請求項１５】　請求項１３または請求項１４による方法に於いて、上記結像工程中に上記第２物体テーブルを、上記目標部分の領域に亘って積分した焦点ずれの自乗を最小にするように、配置し、この焦点ずれが上記投影レンズの焦平面と上記基板の表面との間の第１方向における距離である方法。

【請求項１６】　請求項１３または請求項１４による方法に於いて、上記結像工程がスリット像を上記基板上に走査結像する工程を含み、および上記結像工程中に上記第２物体テーブルを、上記目標部分の領域に亘って積分した焦点ずれの自乗を最小にするように配置し、この焦点ずれが上記投影レンズの焦点面と上記基板の表面の間の上記第１方向に於ける距離を意味する方法。

【請求項１７】　請求項１３ないし請求項１６の何れか一つによる方法に於いて、上記高さマップを作る工程が以下のサブ工程を含む方法：上記基板表面上の上記複数の点の各々の上記第１方向に於ける位置を測定する工程；上記基板表面上の点の位置の各測定と同時に、上記第２物体テーブルの上記第１方向における位置を測定する工程；および上記第２物体テーブルの測定位置の各々を上記高さマップを作るための上記基板表面の対応する測定位置から引く工程。

【請求項１８】　請求項１７による方法に於いて、上記高さマップを作る工程が上記物理的参照面の上記第１方向に於ける位置および同時に上記第２物体テーブルの上記第１方向に於ける位置を測定する初期工程を含む方法。

【請求項１９】　請求項１３ないし請求項１８の何れか一つによる方法であって、更に、上記高さマップを作る工程の前に：露出すべき上記基板上の領域の周辺に近接する上記ウエハ表面上の複数の点の高さを測定する工程、並びに測定した高さから上記基板のための全体の高さおよび傾斜および／またはその高さをマップにすべき上記基板表面のある領域の局部高さまたは傾斜値を決める工程を含む方法。

【請求項２０】　請求項１３ないし請求項１９の何れか一つによる方法であって、更に、上記高さマップを作る工程の前に、上記高さマップを作る際に使用すべきレベルセンサ（１０）を、上記レベルセンサを使って上記基板表面上の少なくとも一つの所定点の垂直位置の複数の測定を、この第２物体テーブルを上記複数の測定の異なるものに対して異なる垂直位置に配置して行うことによって、較正する工程を含む方法。

【請求項２１】　請求項２０による方法に於いて、上記較正工程を上記基板上の複数の異なる露出領域に対して行い、それぞれに得た較正補正値を、型式がこの較正を行ったものに対応する露出領域の高さマップを作る際に適用する方法。

【請求項２２】　請求項１３ないし請求項２１の何れか一つの方法によって製造したデバイス。

【請求項２３】　以下の構成を有するリソグラフィ投影装置を較正する方法であって：放射線の投影ビーム（ＰＢ）を供給するための放射線システム（ＬＡ、Ｅｘ、ＩＮ、ＣＯ）；マスク（ＭＡ）を保持するためのマスクホルダを備える第１物体テーブル（ＭＴ）；基板（Ｗ）を保持するための基板ホルダを備える、第２の、可動物体テーブル（ＷＴ）；並びに上記第２物体テーブルのこのステーションでの位置を測定するための第１位置検出システム（２０ａ）を有する測定ステーション；およびこのマスクの被照射部分をこの基板の目標部分（Ｃ）上に結像するための投影システム（ＰＬ）および上記第２物体テーブルのこのステーションでの位置を測定するための第２位置検出システム（２０ｂ）を有する露出ステーション；上記第２物体テーブルに基板（Ｗ）を設ける工程；上記測定ステーションで、上記基板表面上の複数の点の、上記基板の表面に実質的に垂直な第１方向に於ける位置および同時に上記第２物体テーブルの位置を上記第１位置検出システムを使って測定することによって上記基板の第１高さマップを作る工程；上記露出ステーションで、上記基板表面上の上記複数の点の上記第１方向に於ける位置および同時に上記第２物体テーブルの位置を上記第２位置検出システムを使って測定することによって上記基板の第２高さマップを作る工程；並びに上記第１および第２位置検出システムを較正するために上記第１および第２高さマップを比較する工程；を含む方法。

【請求項２４】　以下の構成を有するリソグラフィ投影装置を用いてデバイスを製造する方法であって：マスク（ＭＡ）を保持するためのマスクホルダを備える第１物体テーブル（ＭＴ）；基板（Ｗ）を保持するための基板ホルダを備える、第２の、可動物体テーブル（ＷＴ）；およびこのマスクの被照射部分をこの基板の目標部分（Ｃ）上に結像するための投影システム（ＰＬ）；上記

第１物体テーブルにパターンを坦持するマスク（ＭＡ）を設ける工程；上記第２物体テーブルに放射線感応層を有する基板（Ｗ）を設ける工程；およびこのマスクの上記被照射部分をこの基板の上記目標部分上に結像する工程；を含み、

複数の基板を露出するために、上記基板を設ける工程および結像する工程を繰返す方法に於いて：この第２物体テーブルに設けた各基板に対して、この基板表面上の複数の点の高さを示す高さマップを作る工程；および上記第２物体テーブルの汚染または機構的欠陥を示すかも知れない不平面度の位置の相関を検出するために逐次得られた基板の高さマップを比較する工程；を有することを特徴とする方法

【請求項２５】　リソグラフィ投影装置であって、

放射線の投影ビーム（ＰＢ）を供給するための放射線システム（ＬＡ、ＩＬ’）；反射性マスク（ＭＡ’）を保持するためのマスクホルダを備える第１の、可動物体テーブル（ＭＴ）；基板（Ｗ）を保持するための基板ホルダを備える、第２の、物体テーブル（ＷＴ）；およびこのマスクの被照射部分をこの基板の目標部分（Ｃ）上に結像するための投影システム（ＰＬ’）；を含む投影装置であって：上記マスクホルダ上に保持された反射性マスクの平面上の複数の点の、参照面に関する、高さを測定しおよびその高さマップを作るように構成および配設された高さマップ作成手段；並びに上記目標部分の露出中に、上記高さマップに従って、上記第１物体テーブルの少なくとも上記第１方向に於ける位置を制御するように構成および配設された制御手段；を有することを特徴とする装置。

【請求項２６】　以下の構成を有するリソグラフィ投影装置を用いてデバイスを製造する方法であって：放射線の投影ビーム（ＰＢ）を供給するための放射線システム（ＬＡ、ＩＬ’）；反射性マスク（ＭＡ’）を保持するためのマスクホルダを備える第１の、可動物体テーブル（ＭＴ）；基板（Ｗ）を保持するための基板ホルダを備える第２物体テーブル（ＷＴ）；およびこのマスクの被照射部分をこの基板の目標部分（Ｃ）上に結像するための投影システム（ＰＬ’）；上記第１物体テーブルにパターンを坦持する反射性マスク（ＭＡ’）を設ける工程；上記第２物体テーブルに放射線感応層を有する基板（Ｗ）を設ける工程；およびこのマスクの上記被照射部分をこの基板の上記目標部分上に結像する工程を含む方法に於いて：上記結像工程の前の、このマスク表面上の複数の点の、上記第１物体テーブル上の参照平面に関する、高さを示す高さマップを作る工程；および上記結像工程中に、この第１物体テーブルを、上記高さマップを参照して、少なくとも上記第１方向に位置決めする工程；に特徴がある方法。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、リソグラフィ装置に於ける、例えば、基板および／またはマスクの、高さ検出およびレベリングに関する。更に詳しくは、この発明は、リソグラフィ投影装置であって：放射線の投影ビームを供給するための放射線システム；マスクを保持するためのマスクホルダを備える第１物体テーブル；基板を保持するための基板ホルダを備える、第２の、可動物体テーブル；このマスクの被照射部分をこの基板の目標部分上に結像するための投影システム；および上記第２物体テーブルを、上記投影システムが上記マスク部分を上記基板上に結像に出来る露出位置と測定位置の間で動かすための位置決めシステム；を含む投影装置に於けるオフアクシスレベリング用システムに関する。

【０００２】

【従来の技術】簡単のために、この投影システムを、以後“レンズ”と呼ぶかも知れないが；この用語は、例えば、屈折性光学素子、反射性光学素子、反射屈折性光学素子、および荷電粒子光学素子を含む、種々の型式の投影システムを包含するように広く解釈すべきである。この放射線システムもこれらの原理の何れかに従って放射線の投影ビームを指向し、成形しまたは制御するために作用する素子を含んでもよく、そのような素子も以下で集合的または単独に“レンズ”と呼んでもよい。その上、この第１および第２物体テーブルを、それぞれ、“マスクテーブル”および“基板テーブル”と呼んでもよい。更に、このリソグラフィ装置は、二つ以上のマスクテーブルおよび／または二つ以上の基板テーブルを有する型式のものでもよい。そのような“多段”装置では、追加のテーブルを並列に使ってもよく、または準備工程を一つ以上のテーブルで実施し、一方、一つ以上の他のテーブルを露出用に使ってもよい。

【０００３】リソグラフィ投影装置は、例えば、集積回路（ＩＣ）の製造に使うことができる。そのような場合、マスク（レチクル）がこのＩＣの個々の層に対応する回路パターンを含んでもよく、このパターンを、感光材料（レジスト）の層で塗被した基板（シリコンウエハ）の露出領域（ダイ）上に結像することができる。一般的に、１枚のウエハが隣接するダイの全ネットワークを含み、それらをレチクルを経て、一度に一つずつ、順次照射する。リソグラフィ投影装置の一つの型式では、全レチクルパターンをダイ上に一度に露出することによって各ダイを照射し；そのような装置を普通ウエハステッパと呼ぶ。普通ステップ・アンド・スキャン装置と呼ぶ代替装置では、このレチクルパターンを投影ビームで与えられた基準方向（“走査”方向）に順次走査し、一方、一般的に、この投影システムが倍率Ｍ（一般的に＜１）とし、ウエハテーブルを走査する速度νとすると、倍率Ｍ掛ける速度であるレチクルテーブルを走査する速度で、ウエハテーブルをこの方向に平行または逆平行に同期して走査することによって各ダイを照射する。ここ

に説明したようなリソグラフィ装置に関する更なる情報は、例えば、国際特許出願ＷＯ９７／３３２０５から収集することができる。

【０００４】極最近まで、リソグラフィ装置は、単一マスクテーブルおよび単一基板テーブルを含んだ。しかし、今や少なくとも二つの独立に可動の基板テーブルがある機械が利用可能である；例えば、国際特許出願ＷＯ９８／２８６６５およびＷＯ９８／４０７９１に記載されている多段装置を参照されたい。そのような多段装置の背後の基本動作原理は、第１基板テーブルがその上にある第１基板を露出するために投影システムの下にある間に、第２基板テーブルが装填位置へ移動でき、露出した基板を排出し、新しい基板を取上げ、この新しい基板に幾つかの初期測定を行い、および次に第１基板の露出が完了するとすぐ、この新しい基板を投影システムの下の露出位置へ移送するために待機し；そこでこのサイクルを繰返すことである。この様にして、機械のスループットをかなり向上することが可能であり、結果としてこの機械の所有コストを改善する。この同じ原理を、露出位置と測定位置の間を動く一つだけの基板テーブルに使えることを理解すべきである。

【０００５】この測定位置で基板に行う測定は、例えば、基板（“ダイ”）上の種々の意図する露出領域、基板上の参照マーカ、および基板テーブル上の基板領域の外側に位置する少なくとも一つの参照マーカ（例えば、基準の）の間の空間関係（ＸおよびＹ方向の）の決定を含んでもよい。そのような情報は、後に投影ビームに関する露出領域の迅速にして正確なＸおよびＹ位置決めを行うために露出位置で使用することが出来；更なる情報については、例えば、ＷＯ９９／３２９４０（Ｐ－００７９）参照。この明細書では、種々の点での、基板表面のＺ位置を基板ホルダの参照面に対して、関連させ高さマップの測定点での準備も記載する。しかし、この参照面は、測定位置でＺ干渉計によって定め、露出位置では、別のＺ干渉計を使用する。従って、二つのＺ干渉計の原点の間の正確な関係を知ることが必要である。

【０００６】

【発明が解決しようとする課題】本発明の目的は、リソグラフィ投影装置に於いて、二つの干渉計システムの原点を関係付ける必要を回避し、且つ露出プロセス中に露出領域の位置決めの付加的改善を可能にする、基板のオフアクシスレベリングをするためのシステムを提供することである。

【０００７】

【課題を解決するための手段】本発明によれば、リソグラフィ投影装置であって：放射線の投影ビームを供給するための放射線システム；マスクを保持するためのマスクホルダを備える第１物体テーブル；基板を保持するための基板ホルダを備える、第２の、可動物体テーブル；このマスクの被照射部分をこの基板の目標部分上に結像するための投影システム；および上記第２物体テーブルを、上記投影システムが上記マスク部分を上記基板上に結像に出来る露出ステーションと測定ステーションの間で動かすための位置決めシステム；を含む投影装置に於いて；上記第２物体テーブルがそれに固定された物理的参照面を有し、並びに：投影装置は、上記測定ステーションに位置し、上記基板ホルダ上に保持された基板の表面上の複数の点の、上記物理的参照面に関する、高さを測定しおよびその高さマップを作るように構成および配設された高さマップ作成手段；上記露出ステーションに位置し、上記第２物体テーブルを上記露出ステーションへ動かしてから、上記物理的参照面の上記基板表面に実質的に垂直な第１方向に於ける位置を測定するための位置測定手段；並びに上記目標部分の露出中に、上記高さマップおよび上記位置測定手段によって測定した上記位置に従って、少なくとも上記第１方向に於ける上記第２物体テーブルの位置を制御するように構成および配設された制御手段と；を有することを特徴とする装置が提供される。

【０００８】本発明の更なる態様によれば、放射線の投影ビームを供給するための放射線システム；マスクを保持するためのマスクホルダを備える第１物体テーブル；基板を保持するための基板ホルダを備える、第２の、可動物体テーブル；およびこのマスクの被照射部分を露出ステーションでこの基板の目標部分上に結像するための投影システムとを含むリソグラフィ投影装置を使うデバイスの製造方法であって：上記第１物体テーブルにパターンを坦持するマスクを設ける工程；上記第２物体テーブルに放射線感応層を有する基板を設ける工程；およびこのマスクの上記被照射部分をこの基板の上記目標部分上に結像する工程を含む方法に於いて：上記結像工程の前の、この第２物体テーブルが測定ステーションにあって、この基板表面上の複数の点の、上記第２物体テーブル上の物理的参照面に関する、高さを示す高さマップを作る工程；この第２物体テーブルを上記露出ステーションへ動かし、上記物理的参照面の上記基板表面に実質的に垂直な第１方向に於ける位置を測定する工程；並びに上記結像工程中に、この第２物体テーブルを、上記高さマップおよび上記物理的参照面の上記第１方向に測定した上記位置を参照して、少なくとも上記第１方向に位置決めする工程に特徴がある方法が提供される。

【０００９】

【発明の実施の形態】この発明によるリソグラフィ投影装置を使う製造プロセスでは、マスクのパターンを、少なくとも部分的にエネルギー感応性材料（レジスト）で覆われた基板上に結像する。この結像工程の前に、この基板は、例えば、下塗り、レジスト塗布およびソフトベークのような、種々の処理を受けるかも知れない。露出後、基板は、例えば、露出後ベーク（ＰＥＢ）、現像、ハードベークおよび結像形態の測定／検査のような、他

の処理を受けるかも知れない。この一連の処理は、デバイス、例えばＩＣの個々の層をパターン化するための基礎として使用する。そのようにパターン化した層は、次に、エッチング、イオン注入（ドーピング）、金属化処理、酸化処理、化学・機械的研磨等のような、全て個々の層の仕上げを意図した種々の処理を受けるかも知れない。もし、幾つかの層が必要ならば、全処理またはその変形を各新しい層に反復しなければならないだろう。結局、デバイスのアレー（ダイ）が基板（ウエハ）上にできる。次に、これらのデバイスをダイシングまたは鋸引のような手法によって互いから分離し、そこから個々のデバイスをキャリヤに取付け、ピンを接続するようにできる。そのようなプロセスに関する更なる情報は、例えば、ピータ・バン・ザントの“マイクロチップの製作：半導体加工の実用ガイド”、第３版、マグロウヒル出版社、1997年、ISBN0-07-067250-4などの書物から得ることができる。

【００１０】本文では、この発明による装置をＩＣの製造に用いるべく特に説明をしてもよいが、そのような装置に多くの他の用途の可能性があることを明確に理解すべきである。例えば、それを集積光学系、磁区メモリ用誘導検出パターン、液晶ディスプレーパネル，薄膜磁気ヘッド等の製造に使ってもよい。当業者は、そのような代替用途の関係では、この本文で使う“レチクル”、“ウエハ”または“ダイ”という用語のどれも、それぞれ、より一般的な用語“マスク”、“基板”および“露出領域”で置換えられると考えるべきであることが分るだろう。

【００１１】本明細書では、“放射線”および“ビーム”という用語を使って、紫外線（例えば、３６５ｎｍ、２４８ｎｍ、１９３ｎｍ、１５７ｎｍまたは１２６ｎｍの波部）、極紫外線（ＥＵＶ）、Ｘ線、電子およびイオンを含むが、それに限定されないあらゆる種類の電磁波放射または粒子束を包含する。やはりここでは、この発明を直交Ｘ、ＹおよびＺ方向の参照系を使って説明し、Ｉ方向に平行な軸周りの回転をＲｉで表す。更に、文脈が別のことを要求するのでなければ、ここで使う“垂直”（Ｚ）という用語は、この装置の何れか特定の方向を意味するのではなく、基板またはマスク面に垂直な方向を指す。

【００１２】

【実施例１】以下に実施例および添付の概略図を参照して本発明を説明する。図１は、この発明によるリソグラフィ投影装置を概略的に示す。この装置は：

● 放射線（例えば、ＵＶまたはＥＵＶ）の投影ビームＰＢを供給するための放射線システムＬＡ、Ｅｘ、ＩＮ、ＣＯ；

● マスクＭＡ（例えば、レチクル）を保持するためのマスクホルダを備え、このマスクを部材ＰＬに関して正確に位置決めするための第１位置決め手段に結合された第１物体テーブル（マスクテーブル）ＭＴ；

● 基板Ｗ（例えば、レジストを塗被したシリコンウエハ）を保持するための基板ホルダを備え、この基板を部材ＰＬに関して正確に位置決めするための第２位置決め手段に結合された第２物体テーブル（基板またはウエハテーブル）ＷＴａ；

● 基板Ｗ（例えば、レジストを塗被したシリコンウエハ）を保持するための基板ホルダを備え、この基板を部材ＰＬに関して正確に位置決めするための第３位置決め手段に結合された第３物体テーブル（基板またはウエハテーブル）ＷＴｂ；

● 測定ステーションで基板テーブルＷＴａまたはＷＴｂ上に保持された基板上に測定（特性表示）プロセスを行うための測定システムＭＳ；および

● 露出ステーションで基板テーブルＷＴａまたはＷＴｂに保持された基板Ｗの露出領域Ｃ（ダイ）上にこのマスクＭＡの被照射部分を結像するための投影システム（“レンズ”）ＰＬ（例えば、屈折若しくは反射屈折性のシステム、ミラーグループまたは視界偏向器アレー）；を含む。

【００１３】ここに示すように、この装置は、透過型である（即ち、透過型マスクを有する）。しかし、一般的に、それは、例えば、反射型でもよい。

【００１４】この放射線システムは、放射線のビームを作る線源ＬＡ（例えば、水銀ランプ、エグザミナレーザ、貯蔵リングまたはシンクロトロンの電子ビームの経路の周りに設けたアンジュレータ、レーザプラズマ源、または電子若しくはイオンビーム源）を含む。このビームを、この照明システムに含まれる種々の光学部品、一例えば、ビーム成形光学素子Ｅｘ、インテグレータＩＮおよびコンデンサＣＯ－ に通して出来たビームＰＢが所望の形状およびその断面での強度分布を有するようにする。

【００１５】このビームＰＢは、続いてマスクテーブルＭＴ上のマスクホルダに保持されているマスクＭＡを横切る。マスクＭＡを通過してから、ビームＰＢは、レンズＰＬを通過し、そのレンズがビームＰＢを基板Ｗの露出領域Ｃ上に集束する。干渉計変位および測定手段ＩＦを使って、基板テーブルＷＴａ、ＷＴｂを第２および第３位置決め手段によって正確に動かすことができ、例えば、異なる露出領域ＣをビームＰＢの経路内に配置する。同様に、第１位置決め手段を使って、例えば、マスクＭＡをマスクライブラリーから機械的に取出してから、このマスクＭＡをビームＰＢの経路に関して正確に配置することができる。一般的に、物体テーブルＭＴ、ＷＴａ、ＷＴｂの移動は、図１にはっきりは示さないが、長ストロークモジュール（粗位置決め）および短ストロークモジュール（微細位置決め）を使って実現する。ウエハステッパの場合は（ステップ・アンド・スキャン装置と違って）、レチクルテーブルを短ストローク

位置決め装置にだけ結合して、マスクの向きおよび位置の微細調整を行ってもよい。

【００１６】この第２および第３位置決め手段は、それらそれぞれの基板テーブルＷＴａ、ＷＴｂを投影システムＰＬの下の露出ステーションおよび測定システムＭＳの下の測定ステーションの両方を含む範囲に亘って位置決めできるように構成してもよい。その代りに、この第２および第３位置決め手段を、基板テーブルをそれぞれの露出ステーションに位置決めするための別々の露出ステーションおよび測定ステーション位置決めシステム並びにこれらの基板テーブルを二つの位置決めシステムの間で交換するためのテーブル交換手段で置換えてもよい。適当な位置決めシステムは、とりわけ上記のＷＯ９８／２８６６５およびＷＯ９８／４０７９１に記載されている。リソグラフィ装置は、多段露出ステーションおよび／または多段測定ステーションを有してもよいこと、並びに測定ステーションの数と露出ステーションの数が互いに異なってもよく、ステーションの全数が基板テーブルの数と等しい必要がないことに注意すべきである。実際、露出および測定ステーションを別々とする原理は、単一基板テーブルにおいても通用する。

【００１７】図示する装置は、二つの異なるモードで使用することができる：１．　ステップ・アンド・リピート（ステップ）モードでは、マスクテーブルＭＴを本質的に固定して保持し、全マスク画像を露出領域Ｃ上に一度に（即ち、単一“フラッシュ”で）投影する。次に、基板テーブルＭＴをＸまたはＹ方向に移動して異なる露出領域ＣをビームＰＢによって照射できるようにし；
２．　ステップ・アンド・スキャン（走査）モードでは、与えられた露出領域Ｃを単一“フラッシュ”で露出しないことを除いて、本質的に同じシナリオを適用する。その代りに、マスクテーブルＭＴが与えられた方向（所謂“走査”方向、例えば、Ｙ方向）に速度ｖで動き得て、投影ビームＰＢにマスク画像上を走査させ；それと共に、基板テーブルＷＴａまたはＷＴｂを同じまたは反対方向にＶ＝Ｍｖの速度で同時に動かす。但し、Ｍはレンズ ＰＬの倍率（典型的には、Ｍ＝１／４または１／５）である。この様にして、比較的大きな露出領域Ｃを、解像度で妥協する必要なく、露出することが出来る。

【００１８】リソグラフィ装置の結像品質に影響する重要な要因は、マスク画像を基板上に集束する精度である。実際には、投影システムＰＬの焦点面の位置を調整するための範囲が限られ、そのシステムの焦点深度が浅いので、これは、ウエハ（基板）の露出領域を投影システムＰＬの焦点面に正確に配置しなければならないことを意味する。これをするためには、勿論、投影システムＰＬの焦点面の位置とウエハの上面の位置の両方を知る必要がある。ウエハは、超高平面度に研磨するが、それにも拘らず、焦点精度に顕著に影響するに十分な大きさの、ウエハ表面の完全平面度からの逸脱（“不平面度”と称する）が起り得る。不平面度は、例えば、ウエハ厚さのばらつき、ウエハ形状の歪みまたはウエハホルダの汚れによって生ずるかも知れない。先の処理工程による構造物の存在もウエハの高さ（平面度）にかなり影響する。本発明では、不平面度の原因が大部分無関係で；ウエハの上面の高さだけを考える。特記しない場合には、以下に称する“ウエハ表面”は、その上にマスク画像を投影する、ウエハの上面を指す。

【００１９】この発明によれば、ウエハを基板テーブルに装填してから、この基板テーブルの物理的参照面に対するウエハ表面の高さZ_{Wefer}をマップにする。このプロセスは、測定ステーションで、レベルセンサと称する第１センサを使ってこの物理的参照面の垂直（Ｚ）位置およびウエハ表面の垂直位置Z_{LS}を複数の点で測定し、並びに第２センサ、例えばＺ干渉計、を使ってこの基板テーブルの垂直位置、Z_{IF}を同じ点で同時に測定することによって行う。図２に示すように、ウエハ表面高さは、$Z_{Wefer}=Z_{LS}-Z_{IF}$として決定する。次に、このウエハを担持する基板テーブルを露出ステーションへ移し、物理的参照面の垂直位置を再び決定する。次に露出プロセス中にウエハを正しい垂直位置に位置決めする際にこの高さマップを参照する。この手順を以下に図３ないし図６を参照して更に詳しく説明する。

【００２０】図３に示すように、最初に基板テーブルを、この基板テーブルに固定した物理的参照面がレベルセンサＬＳの下にあるように動かす。この物理的参照面は、基板テーブル上のＸ、ＹおよびＺ位置がこのリソグラフィ装置でのウエハの処理中に、および最も重要なことには、基板テーブルを測定ステーションと露出ステーション間での移動の際に、変らなければ何か都合のよい面でよい。この物理的参照面は、他の整列マークを含む基準の一部でもよく、且つウエハ表面の垂直位置を測定するのと同じセンサでその垂直位置を測定させるような性質を有すべきである。現在好適な実施例で、この物理的参照面は、中に所謂透過型イメージセンサ（ＴＩＳ）を挿入する基準の反射面である。以下に、このＴＩＳを更に説明する。

【００２１】このレベルセンサは、例えば、米国特許第５，１９１，２００号（Ｐ－００３９）（その中で焦点誤差検出システムと称する）に記載されているような光センサでもよく；その代りに空気圧または容量センサ（例えば）が考えられる。ウエハ面によって反射した投影格子の像と固定検出格子の間に作ったモアレ図形を使うセンサの現在好適な形を、以下にこの発明の第２実施例に関連して説明する。このレベルセンサは、複数の位置の垂直位置を同時に測定してもよく、および各々に対し小さい面積の平均高さを測定して、高さ空間周波数の不平面度を平均してもよい。

【００２２】レベルセンサＬＳによる物理的参照面の垂

直位置の測定と同時に、Ｚ干渉計を使って基板テーブルの垂直位置、Z_{IF}を測定する。このＺ干渉計は、例えば、ＷＯ９９／２８７９０（Ｐ－００７７）またはＷＯＰＰ／３２９４０（Ｐ－００７９）に記載されているような、３、５または６軸干渉計式計測システムの一部でもよい。このＺ干渉計システムは、基板テーブルの垂直位置をＸＹ平面でレベルセンサＬＳの較正した測定位置と同じ位置を有する点で測定するのが好ましい。これは、基板テーブルＷＴの二つの対向する側の垂直位置を、このレベルセンサの測定位置と一致する点で測定し、それらの間を補間／モデリングすることによって行ってもよい。これは、ウエハテーブルがＸＹ平面から傾斜する場合、このＺ干渉計測定がレベルセンサの下の基板テーブルの垂直位置を正しく示すことを保証する。

【００２３】このプロセスを、この第１物理的参照面から、例えば、対角線的に離間した、少なくとも第２物理的参照面で繰返すのが好ましい。すると、二つ以上の位置からの高さ測定を使って参照面を定めることが出来る。

【００２４】一つ以上の物理的参照面の垂直位置と基板テーブルの垂直位置の同時測定は、ウエハ高さをマップにすべき基準となる参照平面を決める点を確立する。上記の種類のＺ干渉計は、絶対センサよりも事実上変位センサであり、それでゼロ合せが必要であるが、広範囲に亙って高度に線形の位置測定を提供する。他方、適当なレベルセンサ、例えば、上記のものは、外部に決めた参照平面（即ち、称呼ゼロ）に関して絶対位置測定を提供するが、小さい範囲に亘ってである。そのようなセンサを使う場合、物理的参照面がレベルセンサの測定範囲の中間で称呼ゼロに位置するまで基板テーブルを垂直に動かし、現在の干渉計Ｚ値を読出すのが好都合である。物理的参照面についての一つ以上のこれらの測定が高さマップ作成のための参照平面を確立するだろう。次に、この参照平面に関してＺ干渉計をゼロに合わせる。この様にして、この参照平面を基板テーブル上の物理的面に関係付け、Z_{Wefer}高さマップを、測定ステーションでのＺ干渉計の初期ゼロ位置および基板テーブルを動かすベースプレートの不平面度のような他の局部因子と無関係に作る。その上、この高さマップをレベルセンサのゼロ位置のドリフトと無関係に作る。

【００２５】図４に示すように、一旦この参照平面を確立すると、高さマップを作るためにウエハ面がレベルセンサの下で走査されるように基板テーブルを動かす。ウエハ面の垂直位置および基板テーブルの垂直位置を既知のＸＹ位置の複数の点で測定し、互いから引いて既知のＸＹ位置でのウエハ高さを得る。これらのウエハ高さ値がウエハ高さマップを形成し、それを適当な形で記録することが出来る。例えば、これらのウエハ高さ値およびＸＹ座標を一緒に所謂目に見えない対に記憶してもよい。その代りに、ウエハ高さ値を採る点を、例えば、ウエハを所定の経路に沿って所定の速度で走査し、所定の間隔で測定することによって、予め決めて、単純なリストまたは高さ値のアレー（任意に測定パターンおよび／または開始点を決める少数のパラメータと共に）がこの高さマップを決めるに十分であるようにする。

【００２６】高さマップ作成走査中の基板テーブルの運動は、大部分ＸＹ平面内だけである。しかし、もし、レベルセンサＬＳが確実なゼロ読みだけを提供する型式であれば、ウエハ面をこのレベルセンサのゼロ位置に保つために、基板テーブルを垂直にも動かす。そこでウエハ高さを、レベルセンサからのゼロ読みを維持するために必要な、Ｚ干渉計によって測定した、基板テーブルのＺ運動から本質的に誘導する。しかし、出力がウエハ高さと線形に関係する、または線形化できる測定範囲がかなり広いレベルセンサを使うのが好ましい。そのような測定範囲は、理想的には、ウエハ高さの最大予測、または許容ばらつきを包含する。そのようなセンサによれば、走査速度がウエハの輪郭を３次元で追跡するための短ストローク基板テーブルの能力によってではなく、センサの応答時間によって制限されるので、この操作中の基板テーブルの垂直運動の必要は減るか、無くなり、走査を速く終えることが出来る。また、直線範囲の広いセンサは、複数の位置（例えば、点のアレー）で高さを同時に測定できるようにする。

【００２７】次に、ウエハテーブルを露出ステーションへ動かし、図５に示すように、この（物理的）参照面を投影レンズの下に配置して、この投影レンズの焦点面に対するその垂直位置の測定が出来るようにする。好適実施例で、これは、その検出器を前の測定で使用した参照面に物理的に結合した、一つ以上の透過型イメージセンサ（以下に説明する）を使って達成する。この透過型イメージセンサは、投影レンズの下のマスクから投影した像の垂直合焦位置を決めることが出来る。この測定を用意して、この参照平面を投影レンズの焦点面に関係付けることが出来、およびウエハ面を最適焦点に保つ、３次元での基板テーブルのための経路を決めることが出来る。これを行える一つの方法は、この走査経路に沿う一連の点に対するＺ、ＲｘおよびＲｙ設定点を計算することである。これらの設定点は、ウエハマップデータと露出スリット像の焦点面の間の差を最小にするように最小自乗法を使って決める。計算を容易にするために、露出スリット像とウエハの相対運動をスリットが静的ウエハに対して動くとして表現することが出来る。すると、この最小自乗基準は、各時間ｔに対し、次の式の最小値を与えるＺ（ｔ）、Ｒｘ（ｔ）およびＲｙ（ｔ）の値を見付けることとして表すことができる：

【００２８】

【数１】

$$LSQ(t)=\frac{1}{s}\cdot\frac{1}{W}\int_{-\frac{s}{2}}^{\frac{s}{2}}\int_{-\frac{W}{2}}^{\frac{W}{2}}\left[w(x,y)-(Z(t)+x\cdot Ry(t)-y\cdot Rx(t))\right]^{2}dxdy \qquad [1]$$

但し、ｗ（ｘ，ｙ）はウエハ高さマップであり、露出スリットは、走査方向の幅ｓおよびこの走査方向に垂直な長さＷの矩形平面であり、その位置はＺ（ｔ）、Ｒｘ（ｔ）およびＲｙ（ｔ）によって定められる。これらの設定点およびウエハ経路は、Ｙ（走査方向の位置）またはｔ（時間）の関数として表すことが出来、それはこれらが$Y=y_0+vt$によって関係付けられているからである。但しy_0は開始点であり、ｖは走査速度である。

【００２９】上記のように、物理的参照面は、中に透過型イメージセンサ（ＴＩＳ）を挿入する面が好ましい。図７に示すように、二つのセンサＴＩＳ１およびＴＩＳ２を、基板テーブル（ＷＴ、ＷＴａ、またはＷＴｂ）の上面に取付けた基準プレートに、ウエハＷが覆う領域の外側に対角線的に対向する位置で取付ける。この基準プレートは、非常に低熱膨張係数で高度に安定した材料、例えばアンバーで作り、平坦な反射上面を有し、それが整列プロセスで使うマークを担持してもよい。ＴＩＳ１およびＴＩＳ２は、投影レンズの空中像の垂直（および水平）位置を直接測定するために使うセンサである。それらは、それぞれの表面に開口を含み、その近くの後ろに露出プロセス用に使う放射線に感応する光検出器が配置されている。焦点面の位置を決めるために、投影レンズが、マスクＭＡ上に設け且つ明・暗コントラスト領域を有するＴＩＳのパターンＴＩＳ－Ｍの像を空間に投影する。次に、基板ステージを水平（１方向または好ましくは２方向に）および垂直に走査し、ＴＩＳの開口がこの空中像があると予測される空間を通過するようにする。ＴＩＳ開口がＴＩＳパターンの像の明・暗部を通過すると、光検出器の出力が変動するだろう。光検出器出力の振幅な変化速度が最大である垂直レベルは、ＴＩＳパターンの像が最大のコントラストを有するレベルを示し、従って最適焦点の平面を示す。この種のＴＩＳの例は、米国特許第４，５４０，２７７号に非常に詳細に記載されている。ＴＩＳの代りに、米国特許第５，１４４，３６３号に記載されているような反射イメージセンサ（ＲＩＳ）も使ってよい。

【００３０】物理的参照面としてＴＩＳの表面を使うことは、ＴＩＳ測定が高さマップのために使う参照平面を投影レンズの焦点面に直接関係付けるという利点を有し、それで高さマップを露出プロセス中にウエハステージのために高さ補正を与えるために直接使用することが出来る。これを図６に図解し、それは、ウエハ表面が投影レンズＰＬの下の正しい位置にあるように、高さマップによって決められた高さでＺ干渉計の制御の下で位置付けられた基板テーブルＷＴを示す。

【００３１】このＴＩＳ表面は、付加的に参照マーカを担持し、その位置をＴＴＬ（レンズを通す）整列システムを使って検出して基板テーブルをマスクに整列してもよい。そのような整列システムは、例えば、ＥＰ－０，４６７，４４５Ａ（Ｐ－００３２）に記載されている。個々の露出領域の整列も、露出領域をウエハステージ上の参照マーカに整列するために測定ステージで行う整列手続によって行うことが出来るか、またはそれによって不要にされてもよい。そのような手続は、例えば、ＥＰ－０９０６５９０Ａ（Ｐ－００７０）に記載されている。

【００３２】生産プロセスで、ステップ・アンド・リピートおよびステップ・アンド・スキャンの両モードで投影システムＰＬによって投影するマスク画像は、単一点ではなく、ＸＹ平面でかなりの領域に亘って拡がることが分るだろう。ウエハ高さがこの領域に亘ってかなりばらつくかも知れないので、焦点合せを単一点だけでなく、この投影領域全体に亘り最適化することが望ましい。本発明の実施例では、これを、基板テーブルＷＴの垂直位置だけでなく、そのＸおよびＹ軸周りの傾き（Ｒｘ，Ｒｙ）も制御することによって達成できる。意図する露出領域の位置および範囲を知り、本発明によって作った高さマップを使って、各露出に対する基板テーブルの最適Ｚ、ＲｘおよびＲｙ設定点を予め計算できる。これは、ウエハが投影レンズの下に位置するときにウエハ高さだけを測定する既知の装置でレベリングするために必要な時間を省略し、従ってスループットを増大する。最適Ｚ、ＲｘおよびＲｙ設定点は、既知の種々の数学的手法を使って、例えば、対話型プロセスを使い、露出領域全体に亘って積分した焦点ずれ（ウエハ表面と理想的焦点面の間の距離として定義する）、すなわちＬＳＱ（ｔ）を最小にすることによって計算してもよい。

【００３３】更なる利点がステップ・アンド・スキャン・モードで可能である。このモードでは、投影レンズがマスクパターンの一部だけの像を露出領域の対応する部分上に投影する。次に、このマスクおよび基板を投影システムＰＬの物体および像焦点面の端から端まで同期して走査し、全マスクパターンを全露出領域上に結像する。実際には、投影レンズを固定し、マスクおよび基板を動かすが、このプロセスをウエハ表面上を動く像スリットに置換えて考えることが屡々便利である。本発明によって予め決めた高さマップで、ＸＹ走査経路（通常、走査は一方向、例えば、Ｙにだけ行う）に整合する一連のＺ、ＲｘおよびＲｙ設定点を計算することが可能である。この一連の設定点は、追加の基準によって、例えば、スループットを増し、または望ましくない振動を誘起するかも知れない垂直加速度または傾斜運動を最小に

することによって最適化できる。離間した一連の設定点を与えられたとすると、多項式またはスプライン適合手順を使って露出に対する走査経路を計算できる。

【００３４】本発明は、与えられた露出に対してウエハをＺ、ＲｘおよびＲｙで最適位置に配置することを意図するものであるが、露出領域全体に亘りウエハ高さが変動するので、ウエハを全領域にわたり充分に焦点合せするように配置出来ないかも知れない。そのような所謂焦点スポットは、露出不良を生ずることがある。しかし、本発明でそのような不具合を予め予測することが出来、修復作業を行うことが出来る。例えば、ウエハを剥がし、露出不良のウエハを更なる処理に悪影響することなく塗直すことが出来る。その代りに、もし、予測した不良がこのウエハ上の一つまたは僅かなデバイスにしか影響せず、他は合格であるならば、予め不良デバイスが出来ると予測できる露出を飛ばすことによってスループットを向上してもよい。

【００３５】焦点スポット検出の更なる利点は、作った高さマップの解析から得ることが出来る。ウエハ高さマップに大域的ウエハ面からの大変位が存在するとき、これは、基板不平面度またはプロセス影響による焦点汚れを示すことがある。幾つかのウエハからのウエハ高さマップの比較は、基板テーブルの汚染または不平面度による焦点汚れを示すことが出来る。焦点汚れが異なるウエハに対して同じまたはほぼ同じ位置に現れるとき、これは、基板ホルダ汚染（所謂“チャック汚れ”）によって生ずる可能性が最も高い。一つのウエハ高さマップから、反復する露出領域（ダイ）からの高さマップ（トポロジー）を比較することもできる。平均高さマップに関して、あるダイに大きな差が生じたなら、ウエハ処理か基板テーブルによる焦点汚れを疑うことが出来る。ウエハ高さマップを比較する代りに、同じ比較をダイ当りの誘導露出経路、または以下に説明する焦点ずれパラメータＭＡ、ＭＳＤまたは移動焦点について行うこともできる。あるダイまたはウエハが平均露出経路または焦点ずれパラメータから大きく外れるとき、焦点スポットも検出できる。

【００３６】上に述べた解析は、全てウエハを露出する前に行うことが出来、且つウエハ排除（処理の影響）または基板ホルダ清掃（チャック汚れ）のような、修復作業を行うことが出来る。これらの方法で、焦点スポットレベルセンサ１０の測定点の大きさに局限できる。これは、焦点スポット検出の従来の方法より遙かに高い解像度を意味する。

【００３７】

【実施例２】本発明の第２実施例を図８に示し、それは露出ステーションおよび測定ステーションだけ、並びに以下の議論に関連する部品だけを示す。この第２実施例は、上に説明した本発明のレベリング原理を、以下に説明するある改良と共に利用する。

【００３８】図８の左の露出ステーションに、計測フレームＭＦに取付けた投影レンズＰＬがマスクＭＡ上のＴＩＳマーカＴＩＳ－Ｍの像を、ウエハテーブルＷＴに取付けたセンサＴＩＳ上に投影するのを示す。この計測フレームは、この装置の他の部品からの振動の伝達から隔離し、微細計測および整列検知に使う受動的部品だけをその上に搭載する。この装置も最も敏感な測定素子の非常に安定なプラットホームと成るように、この計測フレーム全体を、アンバーのような、熱膨張係数の非常に小さな材料で作ってもよい。この計測フレームＭＦ上に取付ける部品には、ミラー３４および３５があり、それに、ウエハテーブルＷＴの側面に取付けた４５°ミラー３１によってＺ干渉計の測定ビームZ_{IF}を導く。基板テーブルのＺ位置をそのＸの運動範囲に亘って測定できることを保証するために、ミラー３４、３５は、対応してＸ方向に大きな広がりを有する。このＺ位置をＹ運動の範囲に亘って測定できることを保証するために、ミラー３１は、ウエハテーブルの全長をカバーする。やはり計測フレームＭＦに取付けられているのは、以下に詳しく説明する、信頼センサ２０ａのビーム発生および受取り部品２１ａ、２２ａである。

【００３９】測定ステーション（図８で右）で、同じ計測フレームＭＦが、露出ステーションのミラー３４、３５と同じ機能を果すミラー３３および３２を坦持し、ミラー３２、３３も、基板テーブルＷＴの必要な運動範囲に対応するために、露出ステーションと全く同じ、Ｘ方向の大きな広がりを有する。ビーム発生部品１１および検出部品１２を含む、レベルセンサ１０も計測フレームＭＦ上に取付けられている。その上、本質的に露出ステーションの信頼センサ２０ａと同じ信頼センサ２０ｂを備える。他の測定装置、例えば、整列モジュールも設けることができる。

【００４０】上に議論したように、物理的参照面（この実施例でも、これをＴＩＳの上面によって与える）を使うことは、ウエハ高さマップをウエハステージに関連付け、それを二つのＺ干渉計のゼロ位置、および上をウエハテーブルが動くベースプレート（石）ＢＰの不平面度のようなある局部因子と無関係にする。しかし、ウエハ高さマップを測定ステーションでＺ干渉計を使って作り、基板テーブル位置を露出ステーションでそこに設けた別のＺ干渉計を使って制御するので、二つのＺ干渉計間のＸＹ位置の関数としての何らかの差がウエハ面を焦点面に配置する精度に影響することがある。本発明で使用する種類の干渉計システムでのこれらの変動の主因は、ミラー３２、３３、３４、３５の不平面度である。４５°ミラー３１は、ウエハテーブルＷＴに取付け、それが露出ステーションと測定ステーションの間で位置が換るとき、それと共に移動する。従って、これらのミラーの不平面度は、露出ステーションでの位置決めに測定ステーションと同じ程度影響し、充分に除去される。し

かし、計測フレームＭＦ上に取付けたミラー３２、３３、３４および３５は、それらそれぞれの干渉計と共に滞留し、それで対応する対３２、３４および３３、３５の表面輪郭に差があれば基板テーブルＷＴの垂直位置決め精度に悪影響することがある。

【００４１】確認センサ２０ａおよび２０ｂは、この装置の初期設定に使い、その後定期的に必要に応じて使い、測定ステーションおよび露出ステーションでＺ干渉計間の差を較正する。これらの確認センサは、ウエハの上面の垂直位置を、その下で基板テーブルを走査するときに、一つ以上の点で測定できるセンサである。信頼センサ２０ａおよび２０ｂは、設計をレベルセンサ１０と同じに出来るが、そうする必要はなく；並びに設定に（および稀な再較正に）だけ、生産ウエハでなく参照ウエハと共に使うので、設計基準が厄介でなく、これを利用して単純なセンサを設計できる。逆に、露出ステーションに投影レンズＰＬが存在することがそのステーションで確認センサに利用できる物理的位置を制限し、これも各確認センサの設計または選択に考慮する必要がある。確認センサを使う較正があらゆる露出の品質に影響するので、それらに高精度が要求される。

【００４２】確認センサを使う較正プロセスでは、参照ウエハを基板テーブルに装填する。この参照ウエハは、裸のシリコンウエハであるのが好ましい。それが通常の裸のＳｉウエハより幾らか平坦である要求はないが、その表面仕上げ（反射率の点で）これらの信頼センサに対して最適化するのが好ましい。この発明の好適実施例では、この参照ウエハがその反射率を最大にし且つ不平面度を最小にするように研磨するのが好ましい。

【００４３】較正手順では、参照ウエハの部分高さマップ（通常通り物理的参照面に関係する）を測定ステーションでレベルセンサ１０ではなく確認センサ２０ｂを使って作る。これは、レベルセンサ１０と同じ方法で行い；物理的参照面（ＴＩＳ）を信頼センサのゼロ点に配置してＺ干渉計をゼロにし、次にウエハを信頼センサの下で走査し、高さマップを確認センサとＺ干渉計の読みの間の差から作る。高さマップを露出ステーションでも、測定ステーションの高さマップと同じ点で信頼センサ２０ａを使って作る。この較正に対し、高さマップは、ウエハを完全に走査する必要はなく；ミラー３２～３５上のＺ干渉計ビームの運動に対応するストリップをカバーする必要があるだけである。（これらのマップを作る順序は、ウエハが基板テーブル上で両方を行う間安定であれば、重要でない。）

【００４４】これらのマップは、同じウエハを表すので、それらの間に差があれば、それらを作るために使った測定システムの間の差によって生じたのだろう。二つの信頼センサは静的であり、それでそれらの高さマップへの影響は、位置依存性でなく、二つの高さマップの正規化および／または静的偏差の減算によって除去できる。残る差があれば、それは位置依存性であり、二つの高さマップを互いから引いて、露出ステーションＺ干渉計を測定ステーションＺ干渉計に関連付ける補正テーブル（ミラーマップ）を作ることができる。これらの補正テーブルは、計測フレームＭＦに取付けたミラー３３、３５および３２、３４間の差の結果であると考えることができ、それで生産プロセスで作ったウエハ高さマップに適用でき、またはマップを作るために使うＺ干渉計の一つを補正するため若しくは露出中に基板テーブルを位置決めするために使うことが出来る。Ｚ干渉計の精密な構造、特に計測フレームミラーおよび基板テーブルミラーによって、各干渉計システムのミラーの不平面度によって生ずるＺ位置の差も１以上の自由度（Ｒｘ、Ｒｙ、Ｒｚ）で傾斜依存性かも知れない。この傾斜依存性をなくするためには、信頼センサを使って種々の異なる傾斜のウエハステージで幾つかの高さマップを作ることが必要かも知れず、それから、必要に応じて、多数の異なる補正テーブル（ミラーマップ）を誘導することが出来る。

【００４５】オフアクシスレベリングの原理を説明したので、今度は第２実施例で使用するその幾らかの更なる改良、並びにその生産プロセスへの組込み方法を説明する。図９および図１０は、それぞれ、測定ステーションおよび露出ステーションで行う工程を示す。二つのウエハテーブルを使用するリソグラフィ装置では、一つのテーブルが図９の工程を行い、一方第２のテーブルは、それらを交換する前に、同時に図１０の工程を行う。以下の説明で、単一ウエハの“寿命”は、測定ステーション（図９）から露出ステーション（図１０）へ行き、戻るまで続く。

【００４６】図９の工程Ｓ１に始り、感光性レジストで塗被したウエハを基板テーブルＷＴ上に装填する。（これは、一般的に、基板テーブルが干渉計システムＩＦの範囲外にある、測定ステーションと別の装填ステーションで行ってもよいことに注意すべきである。）このウエハテーブルを、干渉計計測システムの初期粗ゼロ合せが行えるように、一つ以上の位置検知装置（ＰＳＤ）の捕捉範囲内へ動かす、工程Ｓ２。この初期粗ゼロ合せの後、干渉計システムの微細初期化／ゼロ合せが工程Ｓ３およびＳ４で続く。これら二つの工程は、（二つ以上の）物理的参照面上のレベルセンサ測定（“ＬＳ”で示す）を含み、それが参照平面（ウエハテーブルに固定した）を定め、それに関してウエハ高さマップを測定する。また、二つの整列測定（“ＡＡ”で示す）を同じ物理的参照面上に位置するマーカについて行い、ウエハテーブルに固定した水平参照位置を定める。Ｓ３およびＳ４でのこれらの測定は、この干渉計システムを全ての自由度で効果的にゼロ合せする。

【００４７】このレベリング手順での次の工程は、大域レベル輪郭（ＧＬＳ）と称するＳ５である。以下に更に

詳しく説明する、この工程では、ウエハ捕捉とウエハのレベルセンサによる初期走査を行い、その全体の高さおよび傾斜、並びに後の詳細走査がこのウエハに出入りする点でのその大体の高さを決める。この情報は、ウエハ高さマップ走査用基板テーブル径路を決められるようにする。

【００４８】工程Ｓ６で、ウエハの大域整列を行う。ウエハ上の少なくとも二つの整列マーカを測定し（Ｗ１およびＷ２）、それらのＸＹ位置がＴＩＳ基準上の参照マーカに関して決ったことを意味する。これは、ウエハを走査方向（ｙ）に関して水平に回転する程度（Ｒｚ）を決め、ウエハ高さマップ走査を露出領域軸に平行に行う（即ち、“露出領域上を直進する”）ように、ウエハの回転を補正できるために行う。

【００４９】その後、このレベリング手順は、処理依存補正（ＰＤＣ）に必要な測定を続ける。処理依存補正は、レベルセンサのある形で必要であり、次に説明する。

【００５０】ウエハ高さマップは、ウエハを露出する度毎に作らねばならない。もし、ウエハが既に一つ以上の処理工程を受けていれば、この表面層は、最早純粋な研磨したシリコンではなく、既にこのウエハ上に作った構造または既に作った形態を表すトポロジーもあるかも知れない。異なる表面層および構造がレベルセンサの読みに影響することがあり、特に、その直線性を変えることがある。もし、このレベルセンサが光学的であれば、これらの影響は、例えば、表面構造によって生ずる回折作用によるか、または表面反射率の波長依存性によるかも知れず、且つ常に予測不可能である。必要な処理依存補正を決めるためには、基板テーブルＷＴをレベルセンサ１０の線形または線形化範囲に亘る幾つかの異なる垂直位置に設定して、露出領域またはダイをこのレベルセンサの下で操作する。ウエハ高さ、即ち、ウエハ表面と参照平面の間の物理的距離は、基板テーブルの垂直位置で変るべきでなく；それは、レベルセンサとＺ干渉計の測定値を引くことによって得られる：$Z_{WAFER}=Z_{LS}-Z_{IF}$。従って、もし、Z_{WAFER}の決定した値が基板テーブルの垂直位置で変らなければ、これは、レベルセンサまたはＺ干渉計のどちらかまたは両方が線形でないか、等スケールでないことを意味する。Ｚ干渉計は、ウエハテーブルおよび計測フレーム上のミラーを見るので、線形であると考えられ；実際、少なくとも一旦確認センサの使用によって決めた補正を適用すると、ウエハマップに必要な精度より高度に線形である。従って、ウエハ高さ値に差があれば、それはレベルセンサの非線形性またはスケール誤差から生じたと想定する。それら、およびそれらを観察したときのレベルセンサの読みの知識を使って、このレベルセンサの出力を補正することが出来る。このレベルセンサの現在好適な実施例では、単純なゲイン補正で十分であるが、他のセンサには更に複雑な補正が必要かも知れないことが分った。

【００５１】もし、処理すべきウエハがその上に別の処理を受けている露出領域を有するならば、このウエハ上の各異なる型式の露出領域に対して処理依存補正を決める。逆に、もし、同じまたは類似の処理を受けた露出領域を有するウエハのバッチを露出すべきなら、バッチ当り１回各種の露出領域に対して処理依存補正を測定するだけでよいかも知れない。すると、その補正をその種類の露出領域の高さマップをバッチで作る度毎に適用できる。

【００５２】多くのＩＣ製造では、ウエハをリソグラフィ装置に装填する直前に、それに感光性レジストを付ける。これやその他の理由で、ウエハは、装填して適所にクランプしたとき、基板テーブルと異なる温度であるかも知れない。ウエハが基板テーブルと同じ温度に冷えた（または暖まった）とき、ウエハは真空吸引を使って非常にしっかりとクランプされているので、熱応力が生じることがある。これらは、ウエハの望ましくない歪みを生ずるかも知れない。熱平衡は、工程Ｓ２ないしＳ７が終るときまでに達していそうである。従って、工程Ｓ８で、ウエハの基板テーブルへの真空クランプを解放して、ウエハの熱応力を弛緩させ、次に再適用する。この弛緩は、ウエハの位置および／または傾斜に小さな変化を生ずるかも知れないが、工程Ｓ２ないしＳ４はウエハと無関係であり、Ｓ５およびＳ６は粗測定に過ぎないので、これらは許容できる。この段階でのウエハ位置の変化は、それがウエハの測定ではなく、レベルセンサの較正であるので、処理依存補正に影響しない。

【００５３】真空を再適用後、以後、露出プロセスを完了し、工程Ｓ９でＺマップを行うまで、それは再び解放しない。このＺマップに必要な走査は、露出中にウエハを所望の精度で配置できるように、十分な点の高さを測定しなければならない。測定した点がウエハを露出すべき実際の領域をカバーすることも重要であり；印付けレーンおよび所謂ネズミのかみ傷のような、非露出領域に亘る測定は、誤解を招く結果を生ずるかも知れない。従って、高さマップ作成走査は、手元のウエハ上の露出領域の特定のパターンに最適化しなければならず；以下にこれを更に詳しく説明する。

【００５４】一旦Ｚマップが完成すると、先行整列測定、工程Ｓ１０を行ってから、工程Ｓ１１で、基板テーブルを露出位置へ交換する。この先行整列プロセスでは、基板テーブルに固定したＴＩＳ基準（物理的参照面）上に位置する参照マーカに対する、ウエハ上の多数の整列マーカの位置を正確に決定する。このプロセスは、本発明に特には関連せず、それでここにそれ以上説明しない。

【００５５】交換手順では、高さマップを作ったウエハを坦持する基板テーブルが露出ステーションに到達する。図１０の工程Ｓ１３。工程Ｓ１４で基板テーブルの

粗位置決定を行い、もし必要なら、新しいマスクMAをマスクテーブルMTに装填する。工程S１５。このマスク装填プロセスは、基板テーブル交換と同時に行い、または少なくとも始めてもよい。一旦マスクが適所にあり且つ粗位置決定、工程S１４を行って終うと、工程S１６でセンサTIS１を使って第１TIS走査を行う。このTIS走査は、上に説明したように、このTISが投影レンズの空中像焦点中に位置する、基板テーブルの垂直および水平位置を測定し、焦点面参照をもたらす。図９の工程S９で作った高さマップをTISが位置する物理的表面に関係付けるので、ウエハ表面を別の露出領域に対して焦点面に置くために必要な基板テーブルの垂直位置を直接誘導する。第２TIS走査、工程S１７もセンサTIS２を使って行い、焦点面を参照するための第２点を得る。

【００５６】一旦TIS走査を完了し、焦点面を決定すると、工程S１９での任意に必要なシステム較正（例えば、レンズ加熱効果を補正するための調整）の後に、露出プロセスS１８を行う。この露出プロセスは、一般的に一つ以上のマスクを使う複数露出領域の露出を伴う。複数のマスクを使う場合、マスク交換S２０の後に、一つのTIS走査S１７を繰返して焦点面変更を更新することが出来る。幾つかまたは全ての露出の間に、システム較正工程S１９も繰返してよい。全ての露出の終了後、露出したウエハを坦持する基板テーブルを、その間に図９の工程S１ないしS１０を受けたウエハを坦持する基板テーブルと工程S１３で交換する。露出したウエハを坦持する基板テーブルを装填ステーションへ動かし、新しいウエハを装填できおよびこのサイクルを再開できるように、露出したウエハを取出す。

【００５７】図９の工程S９のウエハ高さマップ作成走査を説明するために、図１１は、シリコン面積を最も良く使うようにウエハ上に配置した種々の形状および大きさの露出領域Cのパターンの例を示す。異なる露出領域Cは、印付けレーンSLによって分離し、“ネズミのかみ傷”として知られる、一般的に三角形の未使用領域が、必然的に矩形露出領域とウエハの曲線縁の間に残される。これらの印付けレーンは、一旦全ての生産プロセスが完了すると（異なるデバイスを分離するように）このウエハを切断するところであり、ある切断技術は、一方向の印付けレーンが全てウエハの幅全体に跨ることを要求するかも知れず；その場合、もしこの装置をステップ・アンド・スキャン・モードで使うべきなら、これらの全ウエハ幅印付けレーンを走査方向（例えば、Y方向）に平行に向けるのが都合がよい。これらの印付けレーンおよびネズミのかみ傷は、露出されないかも知れず、それでこのウエハが幾つかの処理工程または層の被着を受けた後に、それらは露出領域Cとは非常に異なる高さおよび表面特性を有するかも知れない。従って、露出する予定のないこれらの領域の高さ測定を無視することが重要である。

【００５８】レベルセンサの現在好適な実施例は、例えば、九つの点（領域）で高さを同時に測定するために、走査方向に垂直に配置した九つの光学スポットの線形アレーを使用する。（Z干渉計データも対応するレベルセンサ点のアレーで基板テーブルの対応するZ位置データを与えるために内挿できることに注意すべきである。）このスポットのアレーは、この装置で露出できる最広露出領域の幅をカバーするに十分の大きさである。

【００５９】現在好適な走査方式は、このアレーの中心スポットが露出領域の各列の中間線に沿って通るように、スポットのアレーを蛇行経路５０で走査することであり；この中間線は、この露出プロセスで照明したスリットの中間線に対応する。この様にして作ったデータは、最少の再配置または計算で露出走査と直接関係付けることが出来る。この方法は、測定ステーションおよび露出ステーションの両方でZ干渉計ビームを基板テーブルに取付けたミラー３１上の同じ位置に向けて走査を行うので、ミラー不平面度影響の一部もなくする。もし、ダイの列がレベルセンサのスポットのアレーより狭ければ、完全に露出領域内にないスポットから得たデータは無視する。レベルセンサの他の実施例では、スポットのアレーの幅を露出領域の幅に合わせるように調整することが可能かも知れない。

【００６０】もし、ウエハのある露出領域の中心線が残りの中心線より走査方向と垂直な方向にずれているなら、修正走査方式を使うのが有利かも知れない。この状況を図１２に示し、それは１行のダイEの中心線が残りのダイDからずれているのを示す。そのような場合、二つの蛇行経路を走査することによって、マップをより迅速に且つ基板テーブルに対して小さい加速度で作ることができる。図１２に５２で示す一つの経路は、１組の露出領域Dをカバーし、５３で示す他の経路は他の領域Eをカバーする。勿論、露出領域の他の配列は、走査方式に更なる修正を要求するかも知れない。

【００６１】ありそうなことだが、レベルセンサが限られた線形または線形化範囲を有する場合、基板テーブルWTをその下で、ウエハ表面をその範囲内に持込む垂直位置で走査しなければならない。一旦ウエハ表面を見付けてしまえば、ウエハ表面をこの線形または線形化範囲内に保つために基板テーブルWTの垂直位置を調整することは、レベルセンサの読みの基板テーブル位置決めシステムへの閉フィードバックループによって、簡単なことであるが、レベルセンサがウエハの外部から最初に露出領域上に動くときに、ウエハ表面を見付けることはそれ程簡単ではない。蛇行経路に、幾つかのそのような入点があり、図１１の蛇行経路５０上に参照数字５１と矢印によって示し、問題を複合する。

【００６２】入点５１でウエハ表面を見付けるためには、主レベルセンサスポットアレーの前に捕捉スポット

を設けることが可能である。次に、ウエハ上のこの捕捉スポットの反射を、主スポットの場合より広い捕捉範囲を有する検出器へ導く。しかし、これは、追加のハードウェア：主スポットの両側（前／後）の捕捉スポットまたは１方向だけへの走査の制限を要する。必ずしも追加のハードウェアを要しない代替案は、基板テーブルを各入点近くに止め、ウエハ捕捉を行い、およびウエハ表面をレベルセンサの線形または線形化範囲で測定してウエハ表面位置をこの入点で近似することである。しかし、これは、この測定手順をかなり遅くし、スループットの点からは望ましくない結果かも知れない。

【００６３】この発明のこの実施例では、これらの問題を、ウエハ表面を捕捉してから上述の大域レベル輪郭走査（図９の工程Ｓ５）を行うことによって避ける。この大域レベル輪郭走査を図１３を参照して更に説明する。

【００６４】この大域レベル輪郭走査のためには、最初に露出領域Ｃ内の都合の良い点（縁に近いのが好ましい）が単一捕捉スポットおよびレベルセンサ（スポットアレー）の主スポットの下にあるように基板テーブルを配置する。例えば、ウエハ表面を捕捉して主スポットの線形または線形化範囲内に来るまで基板テーブルを走査することによって、ウエハ表面を見付け、次に中央スポット４１が全露出領域の周囲の内部の周りの経路６０を横切るように基板テーブルを走査する。この捕捉手順を以下に詳しく説明する。ウエハ表面高さの測定は、この走査の周りの決った位置で行う。中心スポットは勿論、このアレーの他のスポットがウエハ（の露出領域）の上に当る場合、この中央スポットは勿論、これらのスポットからの測定も行うことが出来る。しかし、測定は、露出領域の外に当るスポットから行うべきでない。図示するように、大域レベル輪郭経路６０は、露出領域の縁をかなり接近して追従する曲りくねった経路である；しかし、より滑らかな経路も使って良く、特に、ウエハに露出領域が良く詰っているときは、円形コース６１で十分であり、より便利かも知れない。この大域レベル輪郭は、ネズミのかみ傷の上を通る円として配設してもよく、その場合、ネズミのかみ傷の上の測定は行わず、またはネズミのかみ傷の上で行った測定のデータは、ウエハの大域高さおよび傾斜の計算には無視する。

【００６５】大域レベル輪郭走査で集めたデータは、二つの目的で使用する。第１に、後に行うべき高さマップ作成走査の入点５１（図１１参照）付近でウエハ高さに関連するデータは、入点５１でのウエハ高さを予測するために使用して、マップ作成走査中、ウエハ表面位置を線形または線形化レベルセンサ範囲内に入れるために基板テーブルを正しい高さに出来るようにする。大抵の場合、このためには僅かなデータ点しか要らず、しかも内挿または外挿によってウエハ高さの十分に正確な予測を可能にするためには入点に特に近い必要もない。このレベルセンサは、（好ましくは）全て線形または線形化範囲内とする必要がある、スポットのアレーをＸ方向に有するので、高さマップ作成走査用に入点５１での局部Ｒｙ傾斜を知ることも望ましい。もし、大域レベル輪郭走査が何れかの入点付近でＹ方向に平行であるか、または平行に近ければ、単一スポットだけから得たデータを使ってＲｙ傾斜を正確に決めることは出来ない。以下に説明するように、Ｘ方向に離間した測定スポットのアレーを有するレベルセンサを使う場合、複数スポットからのデータを使って局部Ｒｙ傾斜を決めることが出来る。勿論、もし、アレーの一部が露出領域外に出るのであれば、その領域内にあるスポットからのデータを選択する。

【００６６】大域レベル輪郭データの第２の用途は、全ウエハのために大域、または平均、高さおよび傾斜（２軸周りの）を決めることである。これは、集めたウエハ高さデータに最も良く適合する平面を決めるために、既知の数学的手法、例えば、最小自乗法によって行う。もし、この大域傾斜（ときには“ウエッジ”と称する）が所定の値より大きいならば、これは装填手順が正しくないことを十分示すかも知れない。その場合、再試行のためにウエハを取出して再装填することが出来、もし失敗し続けるなら排除することさえ出来る。この大域高さおよび傾斜情報を使って、ウエハ上の整列マーカの、基板ステージ上の参照マーカに対する空間関係を正確に決めるために図９の工程Ｓ１０で使う先行整列センサを集束する。この先行整列センサおよびプロセスは、ＷＯ９８／３９６８９（Ｐ－００７０）に詳細に記載してある。

【００６７】ウエハマップ走査中、レベルセンサ１０は、基板テーブルへ連続ＺおよびＲｙフィードバック信号を提供し、レベルセンサ１０をその線形または線形化範囲に維持する。もし、このフィードバックループが止る（レベルセンサ１０が正しい数を供給しない）と、大域ウエハウエッジ（大域Ｒｘによる Z 輪郭）に対応する経路を追従することによってテーブルを制御する。

【００６８】レベルセンサ１０の現在好適な実施例を図１４に示し、付加的に、このセンサの動作の態様を示す図１４Ａないし図１４Ｇを参照して以下に説明する。

【００６９】レベルセンサ１０は、測定ビームb_{LS}をウエハＷ（または物理的参照平面の垂直位置を測定するときはそれ、若しくはその他の反射面）上に向けるビーム発生ブランチ１１およびウエハ表面の垂直位置に依る、反射されたビームの位置を測定する検出ブランチ１２を含む。

【００７０】このビーム発生ブランチでは、光源１１１によって測定ビームを発生し、その光源は、発光またはレーザダイオードのアレーでも、または他で発生して光ファイバによって“照明器”１１１へ送ってもよい。光源１１１が出すビームは、特に幾つかの処理工程終了後、ウエハ表面からの干渉効果の波長依存性を平均するように、広帯域波長、例えば、６００ないし１０５０ｎ

mを含むのが好ましい。照明光学系１１２は、レンズおよびミラーの何か適当な組合せを含んでもよく、光源１１が出す光を集め、投影格子１１３を均一に照明する。投影格子１１３は、図１４Aに詳細に示し、別々の／個々のスポットを作るために格子線をその軸に平行にして分割してもよい細長い格子１１３a、およびウエハ上にこれらの主検出スポットアレーの前に捕捉スポットを作る追加の開口１１３bから成る。この格子の周期は、このウエハ表面位置を測定すべき精度によって一部決められ、例えば、約３０μmでもよい。ウエハ上に投影される格子線が何れの座標軸に対しても平行でないように、この投影格子をその光軸周りに僅かに回転して配置し、それによってxまたはy方向に沿うウエハ上の構造との干渉を避ける。投影レンズ１１４は、投影格子１１３の像をウエハW上に投影するテレセントリック系である。投影レンズ１１４は、投影した像の色収差を最小にしまたは避けるように、本質的に反射光学素子またはそれだけから成るのが好ましく；それは投影ビームが広帯域であり、屈折光学系ではそれらを容易に除去または補償出来ないからである。折返しミラー１１５、１１６を使って投影ビームb_{LS}を投影レンズ１１４に出し入れし、このビーム発生ブランチの部品の都合のよい配置を可能にする。

【００７１】投影ビームb_{LS}は、ウエハに法線に対して、例えば６０°ないし８０°の範囲のかなり大きな角度αで入射し、検出ブランチ１２へ反射する。図１４Bに示すように、もしウエハ表面WSの位置が距離Δhだけ位置WS'へ移動すると、反射ビームr'は、ウエハ表面の移動前のビームrに対して距離２・Δh・sin（α）だけ移動する。図１４Bは、ウエハ表面上の像の外観も示し；入射角が大きいので、この像は格子線に垂直に拡がる。

【００７２】反射ビームを検出光学系１２１によって集め、検出格子１２６上に集束し、その格子は、本質的に投影格子１１３の複製であり、このスポットーアレーパターンに対応するように細分する。検出光学系１２１は、投影光学系１１４と直接相補であり、色収差を最小にするために本質的に反射光学素子またはそれだけから成る。再び折返しミラー１２２、１２３を使って部品の配置を都合よくしてもよい。検出光学系１２１と検出格子１２６の間に、光を４５°に偏光する線形偏光子１２４、並びに格子線に垂直なずれを大きさでこの光の水平および垂直偏光成分間の格子周期に等しくする複屈折結晶１２５が位置する。図１４Cは、この複屈折結晶がないときの検出格子１２６でのビームを示し；それは、一連の交互する明帯域と暗帯域で、明帯域が４５°偏光されている。複屈折結晶１２５は、水平偏光成分の明帯域が垂直偏光成分の暗帯域を埋めるように、水平および垂直偏光状態を変える。従って、図１４Dに示すように、検出格子１２６での照度は、均一なグレーであるが、交互する偏光状態のストリップを有する。図１４Eは、ウエハ表面の垂直位置に依る、このパターンに載せた検出格子１２６を示し；ウエハが称呼ゼロ垂直位置にあるとき、検出格子１２６が一つの偏光状態、例えば、垂直の明帯域の半分と他の状態の半分を覆い閉塞する。

【００７３】検出格子１２６を通過した光を変調光学系１２７によって集め、検出器１２８上に集束する。変調光学系は、二つの偏光状態を交互に通すように、例えば、約５０kHzの周波数の、交番信号によって駆動する偏光変調装置を含む。従って、検出器１２８が見る像は、図１４Fに示す二つの状態の間を交互する。検出器１２８は、高さを測定すべきスポットのアレーに対応する多数の領域に分割する。検出器１２８のある領域の出力を図１４Gに示す。それは、周期が変調光学系のそれに等しい交番信号であり、この振動の振幅は、検出格子上への投影格子の反射像の整列程度、従ってウエハ表面の垂直位置を示す。上述のように、もしウエハ表面が称呼ゼロ位置にあれば、検出格子１２６は、垂直偏光状態の半分と水平偏光状態の半分を遮断し、それで測定した強度が等しく、検出器領域による振動する信号出力の振幅はゼロだろう。ウエハ表面の垂直位置がこのゼロ位置から動くと、検出格子１２６は、水平偏光帯域の多くを通し、垂直偏光帯域の多くを阻止し始める。すると振動の振幅が増すだろう。ウエハ表面の垂直位置の尺度である、この振動の振幅は、ウエハ表面の垂直位置にナノメータで直接線形には関係しない。しかし、補正表または公式を、較正したZ干渉計および未較正のレベルセンサ１０を使って、裸のシリコンウエハの表面の一定の高さを基板テーブルの種々の異なる垂直位置で測定することによって、この装置の初期設定（およびもし必要なら定期的に再較正した）で容易に決めることが出来る。

【００７４】レベルセンサおよびZ干渉計の測定を同時に行ったことを保証するために、同期バスを設ける。この同期バスは、この装置のマスタークロックが発生した非常に安定な周波数のクロック信号を伝える。レベルセンサとZ干渉計の両方をこの同期バスに接続し、このバスからのクロック信号を使ってそれらの検出器のサンプリング点を決める。

【００７５】投影格子１１３を通過した捕捉スポット１１３bが検出格子を通り、そこでそれは、図１５Aに示すように、二つ１３１、１３３は高く設定し、一つ１３２は低く設定した、三つの異なる検出領域に入射する。この低検出領域からの出力を高検出領域から出力から引く。これらの捕捉スポット検出器領域は、ウエハ表面がゼロ位置にあるとき、捕捉スポットが高・低検出領域に同等に当り、引いた出力がゼロであるように配設する。ゼロ位置から離れると、捕捉スポットが検出領域の一つに他より多く当り、引いた出力の大きさが増し、その符号は、ウエハが高過ぎるか低過ぎるかを示す。引いた検出器出力d_{cap}の基板テーブル位置Z_{IF}への依存性を図

１５に示す。検出器出力のこの形は、従来のサーボフィードバックより迅速なゼロ捕捉方法を可能にする。“move-until”と称する、この改善した方法によれば、捕捉スポット検出器がウエハ表面の高過ぎまたは低過ぎを示すとき、基板テーブルのＺ位置アクチュエータが、このウエハ表面を主レベルセンサアレーの線形または線形化範囲内に入れるためにこのステージを適当な方向に動かすように指示する。このウエハステージの運動は、捕捉スポット検出器の出力がトリガレベルt_hまたはt_lを通過するまで続き、その方向に従ってそれが移動する。トリガレベルを横切ると、この装置の制御装置にＺ位置アクチュエータへ命令を出させ、ブレーキ手続を始める。これらのトリガレベルは、この応答時間およびステージ運動にブレーキを掛けるために要する時間中に、このステージがゼロ位置へ動き、または接近するように設定する。その後、このステージを、より正確な主レベルセンサスポットの制御の下でゼロ位置へもたらすことが出来る。これらのトリガ点は、このステージの動力学に従って決め、ゼロ検出器出力の周りに対称に離間する必要はない。この“move-until”制御方式は、線形測定システムを要することなく、迅速且つ頑丈なゼロ捕捉を可能にし、他の状況に使える。

【００７６】上に説明したレベルセンサは、その性能を改善するために更に最適化できる。走査（Ｙ）方向の精度の改善は、適当な信号フィルタリングによって行うことが出来、これは、部分的に処理したウエハ上に見られる特定のプロセス層に適合させてもよい。全方向の追加の改善（特定のプロセス層に対する）は、照明光学系１１２を（投影格子１１３上の照明光の均一性および／または角分布を調整するために）変えることによって、投影格子１１３を変えることによって、または検出システム（検出器の大きさ、位置および／または角分解能並びに検出器数）を調整することによって得てもよい。

【００７７】信頼センサ２０ａ、２０ｂの現在好適な形を図１６および図１７に示す。ビーム発生ブランチ２１は、限られた帯域幅の光を出す光源２１１（例えば、ソリッドステート・レーザダイオードまたはスーパールミネセントダイオード）を含む。それは、計測フレームから離れて位置し、その出力を光ファイバ２１２によって所望の点へ持ってくるのが都合がよい。この光をファイバ終端器２１３から出力し、コリメータ光学系２１４によってビームスプリッタ２１５上に向ける。ビームスプリッタ２１５は、二つの平行測定ビーム

【外１】

b_{u01} および b_{u02}

を作り、それらをウエハＷ上のそれぞれのスポット２３を均一に照明するためにテレセントリック投影光学系２１６によって集束する。この信頼センサの測定ビームの帯域幅は限られるので、投影光学系２１６は、都合よく屈折性素子を使うことが出来る。検出光学系２２１が反射されたビームを集め、それらを、検出器２２３、２２４と検出光学系２２１の間に位置する検出プリズム２２２の縁に集束する。検出プリズム２２２と検出器２２３の側面図である図１７に示すように、測定ビームは、検出プリズム２２２の背面に入射し、傾斜面２２２ａ、２２２ｂから出る。検出器２２３は、二つの検出器素子２２３ａ、２２３ｂから成り、検出プリズム２２２の面２２２ａから出る光が検出器素子２２３ａに達し、面２２２ｂから出る光が検出器素子２２３ｂに達するように配置されている。検出器２２４は、同様である。検出器素子２２３ａおよび２２３ｂの出力は、強度で評価し、減算する。ウエハ表面がゼロ位置にあるとき、これらの測定ビームが検出プリズム２２２の面２２２ａ、２２２ｂ上に対称に当り、等量の光を検出器素子２２３ａ、２２３ｂに向ける。次に、これらが同等の出力を生じ、それで減算した出力がゼロになる。ウエハ表面がこのゼロ位置から動くと、反射したビームの位置は、上下し、面２２２ａ、２２２ｂの一つに他より多く当り、それぞれの検出器素子により多くの光を向ける結果となり、それで減算した出力が比例して変る。ウエハの傾斜は、検出器２２３および２２４の出力の比較によって決めることが出来る。

【００７８】この配置は、本発明の第２実施例で、並びに他の用途で確認センサとして使える、簡単で頑丈な高さおよびレベル検出器をもたらす。この確認センサは、主として測定および露出ステーションのＺ干渉計の初期設定および定期的、例えば、月単位の再較正を意図する。しかし、上に説明した確認センサは、基板テーブルＷＴに対する投影レンズＰＬの焦点面の位置の精密な決定に使うＴＩＳより広い捕捉範囲および迅速な応答を有する。従って、確認確認センサ２０ａは、基板テーブルを最初に露出ステーションへ交換するとき、ＴＩＳの垂直位置の粗い決定をするために有利に使うことが出来る。この確認センサによって測定した高さを先に測定した最善焦点整合位置と関係付け、この最善焦点面の期待する位置に近いＴＩＳ走査のための出発点および範囲を予測するために使う。これは、上に説明したＴＩＳ走査を短く、従って迅速に出来、スループットを改善することを意味する。

【００７９】これらの確認センサに使用できるビームスプリッタ２１５を図１８に示す。ビームスプリッタは、同じガラスからの、および好ましくは等しい厚さの多数のプリズムから成る。三つのプリズム５１、５２、５３から成るビームスプリッタを使って、基本動作原理を説明する。プリズム５１は、断面が台形で、入力ビーム５４がその上面５５の片側近くに入射する。入力ビーム５４の位置は、それがこの上面５５と４５°の第１プリズム５１の一側面５６に当るようになっている。第２プリズム５２は、第１プリズム５１の側面５６に接合され、この入力ビームの所望の部分（本実施例では半分）が第

２プリズム５２の中へ直入してビーム５７を形成し、一方残りは第１プリズム５１内で水平に反射してビーム５８を形成するように、この継目を塗被する。第１プリズム５１で反射されたビーム５８は、そのプリズムの第１側面５６と平行な第２側面５９に当り、下方に反射され、第１プリズム５１の下面を出て、第１プリズム５１の上面と平行な、第３プリズム５３の上面および底面を通る。第２側面５９は、ビーム５８の全内部反射を保証するために、必要に応じて塗被してもよい。第２プリズム５２に入るビーム５７は、第１プリズム５１の側面５６に垂直な、第２プリズム５２の二つの平行面によって内部反射され、第１プリズム５１の上面５５と平行な、第２プリズム５２の底面から出る。それによって、ビーム５７および５８は、平行であるが離れて出力される。ビーム５７、５８間の離隔距離は、プリズム５１および５２の大きさによって決る。プリズム５３は、ビーム５７、５８用の結像光学系を同じに出来るように、両ビームの光路長を均等化するために設ける。プリズム５３は、図示のようにプリズム５２も支持するが、これはある用途では必要ないかも知れない。プリズム５２および５３が接する面でのビーム５７の反射を向上するために、空隙を残し、または適当な被膜を設けてもよい。

【００８０】ビームスプリッタ５０は、簡単で、頑丈で、作るのが容易である。それは、平行（従来の立方体ビームスプリッタが垂直ビームをもたらすのに対して）で光路長が等しい出力ビームをもたらす。この分割面は、偏光選択式に、またはそうでなくでき、後者の場合、入力ビーム強度を所望により均等にまたは不均等に分割することができる。

【００８１】ウエハ表面ＷＳとレベルセンサ１０の測定スポットの焦点面の交差によって定められるＺ方向に垂直な軸周りのウエハステージの傾斜に鈍感であることが、上に説明したレベルおよび信頼センサ、並びにその他の光学的高さセンサの特徴である。これは、これらのセンサがスポットの合焦軸まで外挿した測定スポットの領域に亘って高さを測定するという事実による。この傾斜鈍感性は、Ｚ干渉計および光センサをＸＹ平面で互いの方へ較正するために使うことができる。そのような構成のための手順を図１９およびレベルセンサを参照して説明するが、類似の手順を確認センサまたはその他の類似の光センサに使うことができる。

【００８２】基板テーブルの位置決めシステムを、このＺ干渉計がその一部である多軸干渉計システムに結合し、離間したＺアクチュエータを使ってＸＹ平面の選択した軸の周りに回転を加えるように設定できる。このＺ干渉計測定位置をレベルセンサ測定スポットと整列するために、この位置決めシステムを使ってこのステージを、このＺ干渉計測定位置を通り、例えば、Ｙ軸に平行な軸周りに回転する。Ｚ干渉計によって測定したこのテーブルのＺ位置は、この傾斜中変らないままである。もし、レベルセンサとＺ干渉計を正確に整列すると、ウエハ表面位置も変らないままである。しかし、図１９に示すように、レベルセンサ測定位置がＺ干渉計位置から量δＸだけずれていて、基板テーブルＷＴをその図で仮想線で示す位置へ傾斜すると、レベルセンサ出力に変化δW_{LS}を生ずるだろう。従って、位置ずれδＸ、およびＹ方向の位置ずれδＹは、Ｚ干渉計位置を通過する二つの、好ましくは垂直な軸周りの傾斜によるレベルセンサ出力の変化を検出することによって迅速に決めることができる。そこで、この干渉計測定位置がレベルセンサ測定位置と正確に対向することを保証するように、この干渉計システムまたはレベルセンサ１０のパラメータを調整することができる。

【００８３】レベルセンサが測定スポットのアレーを使う場合、これらのスポットが正確に整列されていることが常に保証される筈がない。従って、上記の手法を使って、Ｚ干渉計位置に関する称呼位置からの個々のスポットの位置ずれを決めることができる。次にこの情報を使って高さマップまたはレベルセンサ出力を補正できる。

【００８４】

【実施例３】第３実施例は、第１実施例のレベリング原理を使用し、それで以下に説明することを除いてその実施例と同じである。この第３実施例は、上に説明した第２実施例のハードウエアおよび改良も使ってよい。しかし、この第３実施例は、露出経路の最適化のために改善した方法を使用する。これを以下に図２０を参照して説明する。

【００８５】上に議論したように、基板ステージが固定で、実際に動くのはウエハであるが、露出スリット像が動くと考えるのが都合がよく且つ妥当である。以下の説明は、この観点から行う。

【００８６】図２０は、以下で使う表記法を示す。明瞭さのために図２０ではスリット像ＳＩをウエハ表面から離して描くが、この最適化手順の目的は、露出中スリット像の焦点面が出来るだけウエハ表面と一致することを保証することであることに注意すべきである。表面がｗ（ｙ）によって定義される１次元ウエハおよびスリット像ＳＩを考えると、このウエハ上の座標に対応する移動平均（経時）焦点ずれＭＡ（ｙ）は次のように計算できる：

【数２】

$$MA(y)=\frac{1}{s}\int_{-\frac{s}{2}}^{\frac{s}{2}}[w(y)-[z(y+v)-vRx(y+v)]]dv \qquad (2)$$

但し、この積分は、走査方向のスリットサイズｓに亘って行い、被積分関数ｗ（ｙ）－［ｚ（ｙ＋ｖ）－ｖＲｘ（ｙ＋ｖ）］は、ある瞬間のウエハの点上の焦点合せ誤差である。同様に、ウエハ上の点に対する移動標準偏差は次のように定義でき：

【数3】

$$MSD^2(y)=\frac{1}{s}\int_{-\frac{s}{2}}^{\frac{s}{2}}[w(y)-\{z(y+v)-vRx(y+v)\}-MA(y)]^2dv \tag{3}$$

それは、ウエハ上のその点の実際の露出中の焦点ずれ時間変動である。露出スリット像の平面とウエハの間の差を最小にするためには、２次焦点ずれ項を使って、次のように定義する：

【数4】

$$MF^2(y)=\frac{1}{s}\int_{-\frac{s}{2}}^{\frac{s}{2}}(w(y)-\{z(y+v)-vRx(y+v)\})^2dv \tag{4}$$

ここでＭＦ（ｙ）を移動焦点と呼ぶ。ＭＦ（ｙ）をＭＡ（ｙ）およびＭＳＤ（ｙ）の項で次のようにも書ける：

【数5】

$$MF^2(y)=MA^2(y)+MSD^2(y) \tag{5}$$

【００８７】これは、露出経路の最適化および露出領域に亘る移動焦点の最小化で、時間、従って走査積分を無視する第１実施例の単純な最小自乗法最適化と違って、移動平均および移動標準偏差の両方を考慮に入れることを意味する。式（３）および（４）は、Ｒｙ（ｔ）依存性を加え、ＭＦを－Ｗ／２から＋Ｗ／２までのＸについて積分することによって容易に２次元に拡張でき、但しＷはＸ方向のスリットの幅である。この最適化を計算するためには、周波数領域表現を使うのが便利である。周波数領域での計算は、露出経路が基板テーブル位置決めシステムの性能に対して最適化されるように、幾つかまたは全ての自由度で過剰の基板ステージ加速度を生ずる結果になるであろう、設定点の高周波変動を濾過して取除けるようにもする。

【００８８】上の議論では、露出スリット像の最適焦点が平面と一致すると仮定したが；これは必ずしもそうではなく；実際は最適焦点が任意の面にあって、所謂焦点面偏差（ＦＰＤ）を生ずるかも知れない。もし、露出スリット領域上のその面の輪郭を、焦点マップｆ（ｘ，ｙ）を作るためにＴＩＳを使って測定または計算できたなら、ウエハ運動を実際の最適上纏綿に対して最適化するように、出来たデータまたは式を上の式に加えることが出来る。

【００８９】この第３実施例の最適化手法は、走査システムに対するよりよい焦点合せおよびより滑らかな基板ステージ経路に終ることが出来、スループットおよび得率を増す。

【００９０】

【実施例４】第４実施例では、レベルセンサがウエハ表面位置の測定で、レジスト層の上面によって反射されたビームとレジスト層の中へ屈折してその底面によって反射されたビームの間の干渉によって生ずるかも知れない誤差を打消すための付加的特徴を備える。さもなければ、この第４実施例は、上に説明した第１ないし第３実施例の何れかと同じかも知れない。

【００９１】上記上面および底面から反射されたビームの干渉は、測定ビームの光学波長および入射角は勿論、レジスト特性およびウエハ表面特性に大きく依存する。広帯域光源および検出器がそのような単一波長干渉を平均するために現在使われている。もし、ウエハ表面位置をスペクトル分解した方法で測定し、それによって広帯域測定ビームの多数の波長に対して別個の測定を行うならば、この平均化原理の改善を実現できる。これを達成するためには、ウエハ表面位置の測定用に時間的または空間的に分離した波長（色）システムを作ることが必要である。これは、レベルセンサの測定原理に以下のような変更を必要とする。

【００９２】レベルセンサへの第１の可能な変更は、連続広帯域光源を異なる波長範囲（色）の光ビームを選択的に発生できるもので置換えることである。これは、例えば、レベルセンサの照明システムの適当な点に異なるカラーフィルタ（例えば、カルーセル上の）を選択的に介在させることにより、幾つかの独立に選択可能な光源を使うことにより、波長を調整できる光源を使うことにより、または小さい広帯域ビームの中にある回転／振動プリズムからの選択したビーム部分を使うことにより達成できる。次に、このレベルセンサを使って、測定ビームの異なる波長の光を使い、各点でウエハ表面の幾つかの測定を行う。

【００９３】もう一つの選択は、広帯域検出器を異なる波長範囲（色）の光を選択的に検出できるもので置換えることである。これは、例えば、検出器の前の検出光学系にカラーフィルタを配置することにより、プリズムを使って測定ビームを異なる波長に空間的に分割し、それからこの異なる波長のビームを別々の検出器で検出することにより、またはウエハ表面位置を測定するために広帯域反射ビームをスペクトルで解析するその他の方法により達成できる。

【００９４】当然、組合せアプローチを使い、それによって投影システムと検出システムの両方をスペクトル分解するようにすることも可能である。

【００９５】干渉効果がなければ、各測定（各波長に対する）が同じ結果を出すべきであり；従って、そのような測定で、もし違う結果を得たならば、これは、上の最初の段落で触れたような効果の存在を示す。そこで、多種多様な手法を使って、改良したウエハ表面位置測定を導き出すことが出来る。例えば、矛盾する結果は、補正または破棄してもよい。過半数投票の手法も使ってもよい。その代りに、ウエハ表面位置のスペクトル計測に基づいて、レジストおよびウエハ表面特性のスペクトル応

答を記述するモデルによって実際の位置を誘導してさえよい。

【００９６】記述した干渉効果は、ウエハ表面上の測定ビームの入射角にも依るので、この効果を評価し、次いでそれを補正するように、この入射角も変えたいかも知れない。従って、レベルセンサへの更なる可能な変更は、それをウエハ表面位置が異なる入射角で測定ビームを使って行えるようにすることである。これを達成する一つの方法は、ウエハ上の同じスポットであるが、別々の投影および検出光学系に対して異なる入射角を有する多重測定ビームを形成することである。その代りに、同じ投影および検出システムが種々の測定ビームに関係した異なる光軸を包含するように光学系を変えることが出来る。時間的に変動する入射角を作るもう一つの選択は、レベルセンサの光学系に回転／並進折返しミラー（またはその他の可動部品）を使うことである。

【００９７】上に説明した波長依存性同様、干渉効果がなければ、異なる入射角での測定が同じ結果を出すべきである。従って、矛盾（入射角での変動）があれば、避け、補償し、または同じ方法でモデル化できる。

【００９８】上記の付加的特徴および改善は、勿論、一緒にまたは別々に、およびここに説明した以外の光学センサに使ってもよい。

【００９９】

【実施例５】この発明の第５実施例を図２１に示す。この発明の第５実施例は、露出放射線として、例えば、９ないし１６ｎｍの範囲の波長の極紫外線（ＥＵＶ）、および反射性マスクＭＡ’を使用するリソグラフィ装置である。少なくとも機能的に、この第５実施例の部品は、一般的に第１実施例のものと同じであるが、それらは使用する露出放射線波長に適合するようにされ、それらの配置は、反射性マスクの使用によって必要とされるビーム経路に適応するように調整されている。必要かも知れない特別の改作には、照明および投影光学系ＩＬ’、ＰＬ’を露出放射線の波長に最適化することがあり；これは、一般的に屈折性ではなく反射性の光学素子を使うことを伴う。ＥＵＶ放射線に使う照明光学系ＩＬ’の例は、ヨーロッパ特許出願第００３００７８４，６号（Ｐ－０１２９）に記載されている。

【０１００】反射性マスクを使うリソグラフィ装置と透過性マスクを使うものとの間の重要な差は、反射性マスクではマスクの不平面度が、下流の光学系、即ち、投影レンズＰＬ’の光路長によって増加する、ウエハ上の位置誤差になることである。これは、マスクの高さおよび／または傾斜偏差がマスク上の照明ビームの有効入射角を局部的に変え、従ってウエハ上の像形態のＸＹ位置を変えるからである。

【０１０１】この発明の第５実施例によれば、マスクの不平面度の影響は、露出に先立ってマスクの高さマップを作り、露出中にＺ、ＲｘおよびＲｙの少なくとも一つでのマスク位置を制御することによって回避または軽減される。この高さマップは、上に説明したのと類似の方法（即ち、測定ステーションでのマスクのオフアクシスレベリング）で作れるが；しかし、それを露出ステーションのマスクで作ってもよく、それは高さマップを物理的参照面に関連付ける必要を無くするかも知れない。露出または露出走査（露出経路）中のマスクの最適位置の計算は、上に説明したのと同等でよいが、それをウエハおよびマスク露出経路の最適化と結合してもよい。しかし、マスクに対しては、傾斜偏差がウエハでの位置に大きな影響を有するので、その最適化計算に重きを置いた方が有利かも知れない。

【０１０２】この発明によるリソグラフィ投影装置は、二つ（以上）の基板テーブルおよび／または二つ（以上）のマスクテーブルを含んでもよいことにはっきりと注目すべきである。そのようなシナリオでは、第１基板テーブル上の第１基板が測定ステーションで高さマップ作成を受け、一方第２基板テーブル上の第２基板が同時に露出ステーションで露出を受け；および複数マスクテーブルの場合、同様であることが可能である。そのような構成は、スループットを非常に大きくすることが出来る。

【０１０３】この発明は、基板レベリングだけ、マスクレベリングだけ、または基板レベリングとマスクレベリングの組合せに適用できることにもはっきりと注目すべきである。

【０１０４】上にこの発明の特定の実施例を説明したが、この発明を説明したのと別の方法で実施してもよいことが分るだろう。この説明は、この発明を限定することを意図しない。

【図面の簡単な説明】

【図１】この発明の第１実施例によるリソグラフィ投影装置を示す。

【図２】レベルセンサおよびＺ干渉計による測定からウエハ高さを決める方法を示す図である。

【図３】本発明によるオフアクシスレベリング手順の種々の工程を示す図である。

【図４】本発明によるオフアクシスレベリング手順の種々の工程を示す図である。

【図５】本発明によるオフアクシスレベリング手順の種々の工程を示す図である。

【図６】本発明によるオフアクシスレベリング手順の種々の工程を示す図である。

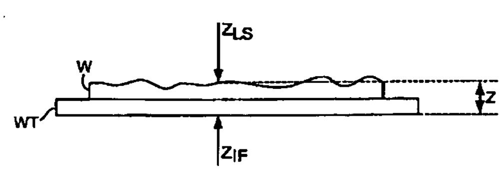
【図７】本発明によるオフアクシスレベリング手順で使用するセンサおよび基準を示す基板テーブルの平面図である。

【図８】この発明の第２実施例の露出ステーションおよび測定ステーションの側面図である。

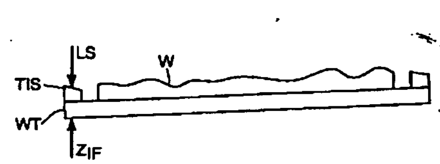
【図９】この発明の第２実施例の測定出ステーションで実施する測定プロセスの種々の工程を示す流れ図であ

る。
【図１０】本発明の第２実施例の露出ステーションで実施する露出プロセスの種々の工程を示す流れ図である。
【図１１】本発明の高さマップを測定するために使用できる走査パターンを示す線図である。
【図１２】本発明の高さマップを測定するために使用できる代替走査パターンを示す線図である。
【図１３】本発明の第２実施例の大域レベル輪郭プロセスを示す線図である。
【図１４】この発明に使用できるレベルセンサの現在好適な実施例の構造を示す。
【図１４Ａ】この発明に使用できるレベルセンサの投影格子を詳細に示す。
【図１４Ｂ】この発明に使用できるレベルセンサの動作態様を示す。
【図１４Ｃ】この発明に使用できるレベルセンサの検出格子の動作態様を示す。
【図１４Ｄ】この発明に使用できるレベルセンサの検出格子の動作態様を示す。
【図１４Ｅ】この発明に使用できるレベルセンサの検出格子の動作態様を示す。
【図１４Ｆ】この発明に使用できるレベルセンサの検出器の動作態様を示す
【図１４Ｇ】この発明に使用できるレベルセンサの検出器の出力を示す。
【図１５】図１４のレベルセンサの捕捉スポットの検出器出力対基板テーブル位置を示すグラフである。
【図１５Ａ】図１４のレベルセンサの捕捉スポット用検出器部分を示す線図である。
【図１６】この発明の第２実施例に使用できる信頼センサの現在好適な実施例を示す線図である。
【図１７】この発明の第２実施例に使用できる信頼センサの現在好適な実施例を示す線図である。
【図１８】図１６および図１７の信頼センサに使用できるビームスプリッタの線図である。
【図１９】この発明の実施例に使用できるＺ干渉計較正手順を説明するために使用する線図である。
【図２０】この発明の第３実施例による露出経路最適化手順を説明する際に使用する表記法を示す線図である。
【図２１】この発明の第５実施例によるリソグラフィ投影装置を示す。
【符号の説明】
Ｃ　目標部分
ＣＯ　コンデンサ
Ｅｘ　ビーム成形光学素子
ＩＦ　位置検出手段
ＩＬ’　照明光学系
ＩＮ　インテグレータ
ＬＡ　線源
ＭＡ　マスク
ＭＡ’　反射性マスク
ＭＴ　マスクテーブル
ＰＢ　投影ビーム
ＰＬ　投影システム
ＰＬ’　投影システム
Ｗ　基板
ＷＴ　基板テーブル
１０　レベルセンサ
２０ａ　第１位置検出システム
２０ｂ　第２位置検出システム
１１１　放射線源
１１３　投影格子
１１４　投影光学系
１２１　検出光学系
１２６　検出格子
１２８　検出器

【図２】



【図３】



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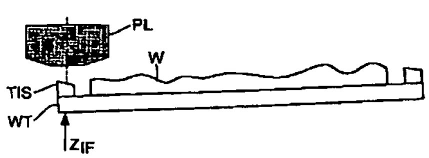
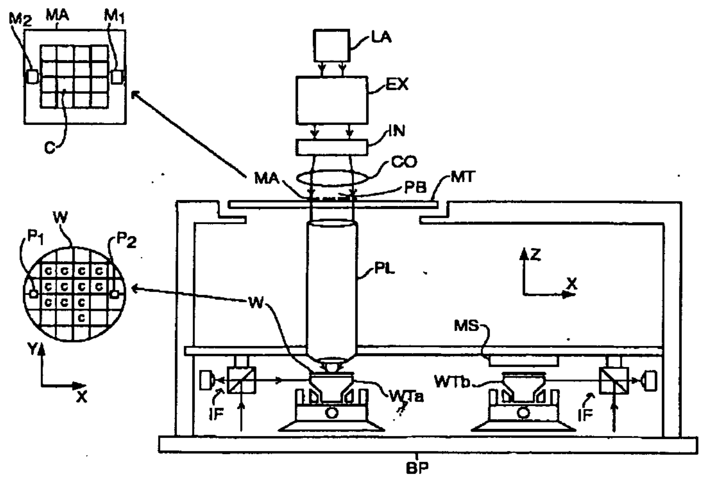


【図１４Ａ】

【図１４Ｄ】

【図1】



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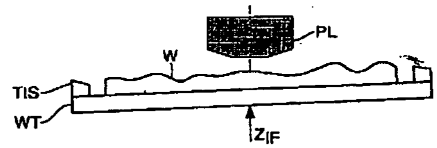
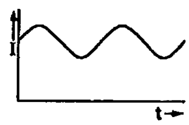
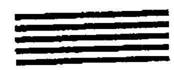


【図１４Ｇ】

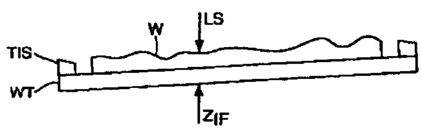


【図１４Ｃ】

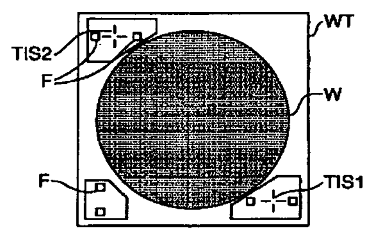


【図１４Ｅ】

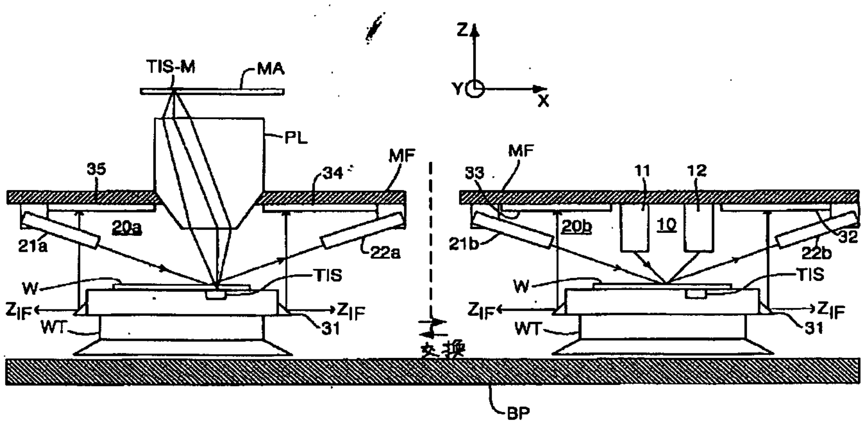
【図4】



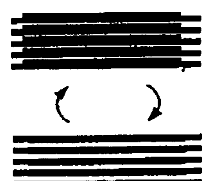
【図7】



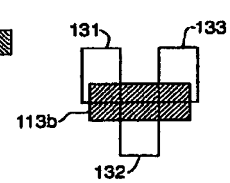
【図8】



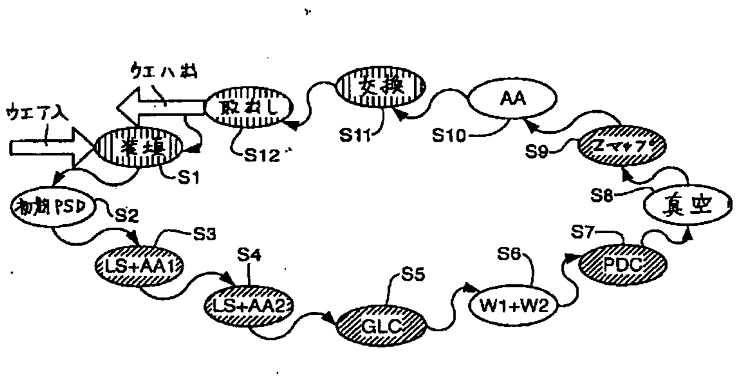
【図１４Ｆ】



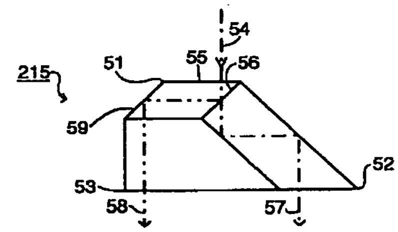
【図１５Ａ】



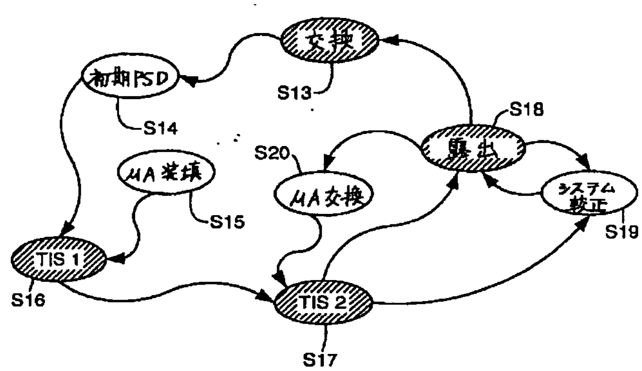
【図９】



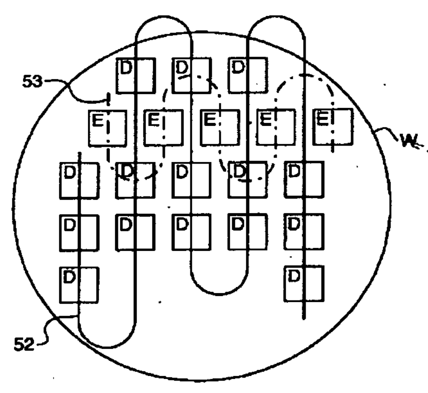
【図１８】



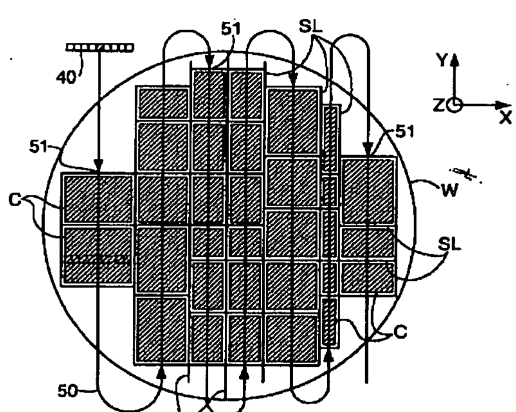
【図１０】



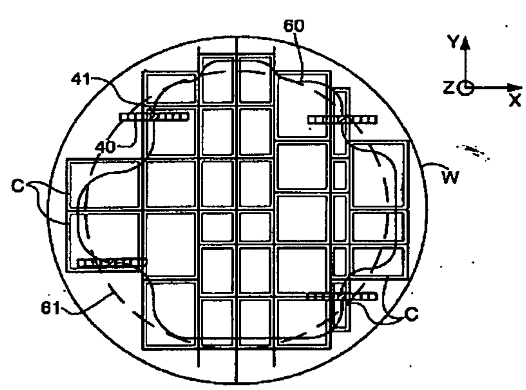
【図１２】



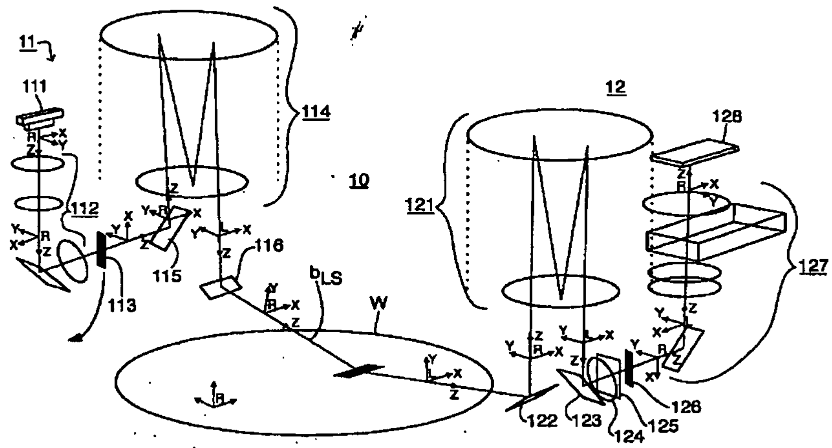
【図１１】



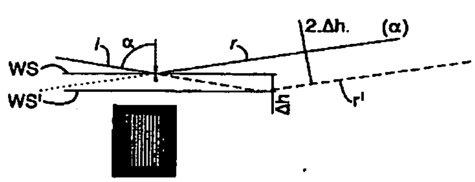
【図１３】



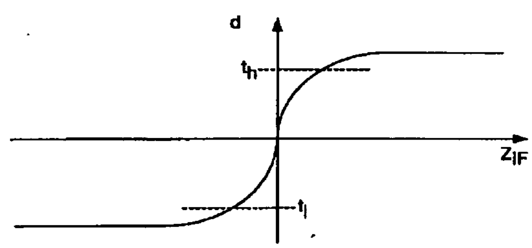
【図１４】



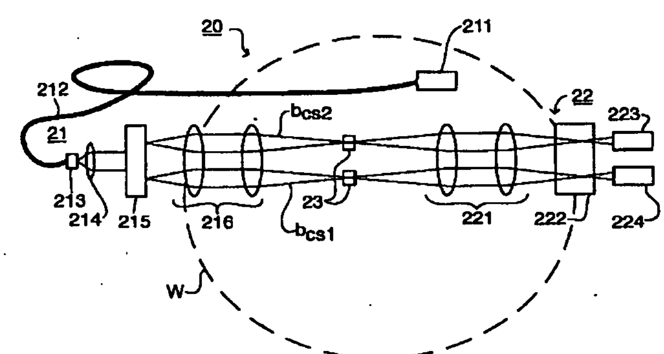
【図１４Ｂ】



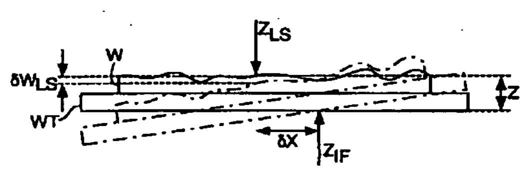
【図１５】



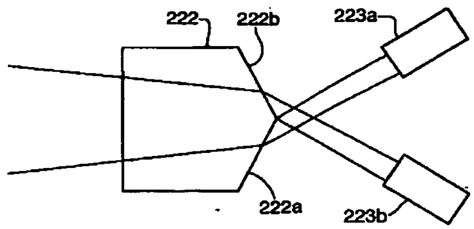
【図１６】



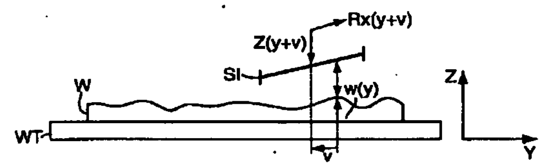
【図１９】



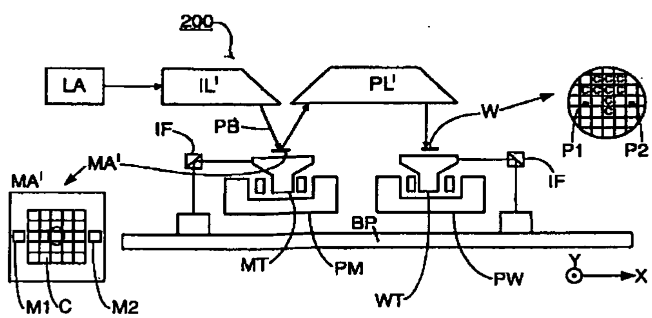
【図１７】



【図２０】



【図２１】



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【外国語明細書】

1 Title of Invention

OFF-AXIS LEVELING IN LITHOGRAPHIC PROJECTION APPARATUS

2 Claims

1. A lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a mask holder for holding a mask;

a second, movable object table provided with a substrate holder for holding a substrate;

a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate; and

a positioning system for moving said second object table between an exposure station, at which said projection system can image said mask portion onto said substrate, and a measurement station; characterized in that

said second object table has a physical reference surface fixed thereto;

and by:

height mapping means located at said measurement station and constructed and arranged to measure the height, relative to said physical reference surface, of a plurality of points on the surface of a substrate held on said substrate holder and to create a height map thereof;

position measuring means located at said exposure station for measuring the position of said physical reference surface in a first direction substantially perpendicular to said substrate surface, after movement of said second object table to said exposure station; and

control means constructed and arranged to control the position of said second object table in at least said first direction, during exposure of said target portion, in accordance with said height map and said position measured by said position measuring means.

2. Apparatus according to claim 1 wherein said control means is further arranged to control the tilt of said second object table about at least one axis perpendicular to said first direction in accordance with said height map.

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3. Apparatus according to claim 1 or 2 wherein said height mapping means comprises a level sensor constructed and arranged to simultaneously measure the position in said first direction of a linear array of points.

4. Apparatus according to claim 1, 2 or 3, wherein said height mapping means comprises a level sensor constructed and arranged to measure the position of a measurement beam reflected by the surface whose position in said first direction is to be measured.

5. Apparatus according to claim 4 wherein said level sensor comprises: a projection grating; projection optics for projecting an image of said projection grating onto the surface whose position in said first direction is to be measured; a detection grating, detection optics for focusing light reflected by said surface to form on said detection grating an image of said projection grating; and a detector for detecting Moiré patterns formed by the overlay of said image of said projection grating on said detection grating.

6. Apparatus according to claim 5 wherein said level sensor further comprises a radiation source constructed and arranged to illuminate said projection grating with polychromatic radiation and wherein said projection optics and said detection optics consist essentially of reflective optical elements.

7. Apparatus according to any one of the preceding claims wherein said height mapping means comprises a level sensor for detecting the position in said first direction of the surface of said substrate at said plurality of points and position detection means for detecting the position in said first direction of said second object table simultaneously with measurements by said level sensor.

8. Apparatus according to claim 7 wherein said position detection means comprise an interferometer.

9. Apparatus according to any one of the preceding claims wherein said position measuring means comprises an image sensor mounted to said second object table and said physical reference surface comprises an upper surface of said image sensor.

10. Apparatus according to any one of the preceding claim, wherein said position measuring means is constructed and arranged to measure the position of said physical reference surface relative to the focal plane of said projection system.

11. Apparatus according to any one of the preceding claims wherein said second object table has a plurality of spaced-apart physical reference surfaces; and said height mapping means is constructed and arranged to measure the height of said plurality of points relative to a reference plane defined by said plurality of physical reference surfaces.

12. Apparatus according to any one of the preceding claims further comprising:

a second height mapping means located at said exposure station constructed and arranged to measure the height, relative to said physical reference surface, of said plurality of points on the surface of a substrate held on said substrate holder and to create a height map thereof; and

calibration means constructed and arranged to compare height maps of a single substrate prepared by each of said first and second height mapping means to derive a relative calibration for separate position detection systems provided at said measuremen and exposure stations.

13. A method of manufacturing a device using a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a mask holder for holding a mask;

a second, movable object table provided with a substrate holder for holding a substrate; and

a projection system for imaging irradiated portions of the mask onto target

providing a mask bearing a pattern to said first object table;

providing a substrate having a radiation-sensitive layer to said second object table; and

imaging said irradiated portions of the mask onto said target portions of the substrate; characterized by the steps of:

before said step of imaging, generating, with the second object table at a measurement station, a height map indicating the height of a plurality of points on the substrate surface relative to a physical reference surface on said second object table;

moving the second object table to said exposure station and measuring the position of said physical reference surface in a first direction substantially perpendicular to said substrate surface; and

during said step of imaging, positioning the second object table in at least said first direction by reference to said height map and said measured position in said first direction of said physical reference surface.

14. A method according to claim 13 wherein, during said step of imaging, said second object table is oriented about at least one axis perpendicular to said first direction by reference to said height map.

15. A method according to claim 13 or 14 wherein said second object table is positioned during said imaging step so as to minimize the squared defocus integrated over the area of said target portion, wherein the defocus comprises the distance in said first direction between the focal surface of said projection lens and the surface of said substrate.

16. A method according to claim 13 or 14 wherein said step of imaging comprises scan imaging a slit image onto said substrate, and said second object table is positioned during said imaging step so as to minimize the squared defocus integrated over the duration of said scanning exposure and the area of said slit image, wherein the defocus comprises the distance in said first direction between the focal surface of said projection lens and the surface of said substrate.

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17. A method according to any one of claims 13 to 16 wherein said step of generatin a height map comprises the substeps of:

measuring the position in said first direction of each of said plurality of points o said substrate surface;

simultaneously with each measurement of the position of a point on said substrate surface, measuring the position in said first direction of said second object table; and

subtracting each measured position of said second object table from the corresponding measured position of said substrate surface to generate said height map.

18. A method according to claim 17 wherein said step of generating a height map comprises the initial step of measuring the position in said first direction of said physic reference surface and simultaneously the position in said first direction of said second object table.

19. A method according to any one of claims 13 to 18 comprising the further steps, before said step of generating a height map, of:

measuring the height of a plurality of points on said wafer surface adjacent the perimeter of areas on said substrate that are to be exposed, and determining from the measured heights an overall height and tilt for said substrate and/or local height or tilt values in certain regions of said substrate surface whose height is to be mapped.

20. A method according to any one of claims 13 to 19 further comprising the step, before said step of generating a height map, of calibrating a level sensor to be used in generating said height map by using said level sensor to make a plurality of measurements of the vertical position of at least one predetermined point on said substrate surface with the second object table being positioned at different vertical positions for different ones of said plurality of measurements.

21. A method according to claim 20 wherein said step of calibrating is performed fc a plurality of different exposure areas on said substrate and respective resulting

calibration corrections are applied in generating the height map for exposure areas corresponding in type to those for which the calibration was performed.

22. A device manufactured according to the method of any one of claims 13 to 21.

23. A method of calibrating a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a mask holder for holding a mask;

a second, movable object table provided with a substrate holder for holding a substrate; and

a measurement station having a first position detection system for measuring the position of said second object table at said measurement station;

an exposure station having a projection system for imaging irradiated portions o the mask onto target portions of the substrate and a second position detection system fc measuring the position of said second object table at said exposure station; the method comprising the steps of:

providing a substrate to said second object table;

at said measurement station, generating a first height map of said substrate by measuring the position in a first direction, substantially perpendicular to the surface of said substrate, of a plurality of points on said substrate surface and simultaneously measuring the position of said second object table using said first position detection system;

at said exposure station, generating a second height map of said substrate by measuring the position in said first direction of said plurality of points on said substrate surface and simultaneously measuring the position of said second object table using said second position detection system; and

comparing said first and second height maps to calibrate said first and second position detection systems.

24. A method of manufacturing devices using a lithographic projection apparatus comprising:

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a first object table provided with a mask holder for holding a mask;

a second, movable object table provided with a substrate holder for holding a substrate; and

a projection system for imaging irradiated portions of the mask onto target portions of the substrate; the method comprising the steps of:

providing a mask bearing a pattern to said first object table;

providing a substrate having a radiation-sensitive layer to said second object table and

imaging said irradiated portions of the mask onto said target portions of the substrate;

said steps of providing a substrate and imaging being repeated to expose a plurality of substrates; characterized by the steps of:

generating, for each substrate provided to second object table, a height map indicating the height of a plurality of points on the substrate surface; and comparing the height maps of successively provided substrates to detect correlations in the locations of any unflatnesses that may be indicative of contamination or systematic faults of said second object table.

25. A lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first, movable object table provided with a mask holder for holding a reflective mask;

a second, object table provided with a substrate holder for holding a substrate; and

a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate; characterized by

height mapping means constructed and arranged to measure the height, relative to a reference surface, of a plurality of points on the plane of a reflective mask held on said mask holder and to create a height map thereof; and

control means constructed and arranged to control the position of said first object table in at least said first direction, during exposure of said target portion, in accordance with said height map.

26. A method of manufacturing a device using a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first, movable object table provided with a mask holder for holding a reflective mask;

a second object table provided with a substrate holder for holding a substrate; and

a projection system for imaging irradiated portions of the mask onto target portions of the substrate; the method comprising the steps of:

providing a reflective mask bearing a pattern to said first object table;

providing a substrate having a radiation-sensitive layer to said second object tabl and

imaging said irradiated portions of the mask onto said target portions of the substrate; characterized by the steps of:

before said step of imaging, generating, a height map indicating the height of a plurality of points on the mask surface relative to a reference plane on said first object table; and

during said step of imaging, positioning the first object table in at least said first direction by reference to said height map.

3 Detailed Description of Invention

The present invention relates to height detection and levelling, for example of the substrate and/or mask, in lithographic apparatus. More particularly, the invention relates to a system for off-axis levelling in lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a mask holder for holding a mask;

a second, movable object table provided with a substrate holder for holding a substrate;

a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate; and

a positioning system for moving said second object table between an exposure position, at which said projection system can image said mask portion onto said substrate, and a measurement position.

For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, catadioptric systems, and charged particle optics, for example. The radiation system may also include elements operating according to any of these principles for directing, shaping or controlling the projection beam, and such elements may also be referred to below, collectively or singularly, as a "lens". In addition, the first and second object tables may be referred to as the "mask table" and the "substrate table", respectively. Further, the lithographic apparatus may be of a type having two or more mask tables and/or two or more substrate tables. In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the mask (reticle) may contain a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged

onto an exposure area (die) on a substrate (silicon wafer) which has been coated with a layer of photosensitive material (resist). In general, a single wafer will contain a whole network of adjacent dies which are successively irradiated via the reticle, one at a time. In one type of lithographic projection apparatus, each die is irradiated by exposing the entire reticle pattern onto the die in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus — which is commonly referred to as a step-and-scan apparatus — each die is irradiated by progressively scanning the reticle pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the wafer table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the wafer table is scanned will be a factor M times that at which the reticle table is scanned. More information with regard to lithographic devices as here described can be gleaned from International Patent Application WO 97/33205, for example.

Until very recently, lithographic apparatus contained a single mask table and a single substrate table. However, machines are now becoming available in which there are at least two independently moveable substrate tables; see, for example, the multi-stage apparatus described in International Patent Applications WO98/28665 and WO98/40791. The basic operating principle behind such multi-stage apparatus is that, while a first substrate table is at the exposure position underneath the projection system for exposure of a first substrate located on that table, a second substrate table can run to a loading position, discharge a previously exposed substrate, pick up a new substrate, perform some initial measurements on the new substrate and then stand ready to transfer the new substrate to the exposure position underneath the projection system as soon as exposure of the first substrate is completed; the cycle then repeats. In this manner it is possible to increase substantially the machine throughput, which in turn improves the cost of ownership of the machine. It should be understood that the same principle could be used with just one substrate table which is moved between exposure and measurement position.

The measurements performed on the substrate at the measurement position may, for example, include a determination of the spatial relationship (in X & Y directions) between various contemplated exposure areas on the substrate ("dies"),

reference markers on the substrate and at least one reference marker (e.g. fiducial) located on the substrate table outside the area of the substrate. Such information can subsequently be employed at the exposure position to perform a fast and accurate X and Y positioning of the exposure areas with respect to the projection beam; for more information see WO 99/32940 (P-0079), for example. This document also describes the preparation at the measurement position of a height map relating the Z position of the substrate surface at various points to a reference plane of the substrate holder. However the reference plane is defined by a Z-interferometer at the measurement position and a different Z-interferometer is used at the exposure position. It is therefore necessary to know accurately the relationship between the origins of the two Z-interferometers.

An object of the present invention is to provide a system for off-axis levelling a substrate in a lithographic projection apparatus that avoids the need to relate the origins of two interferometer systems and enables additional improvements in positioning of the exposure areas during exposure processes.

According to the present invention there is provided a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a mask holder for holding a mask;

a second, movable object table provided with a substrate holder for holding a substrate;

a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate; and

a positioning system for moving said second object table between an exposure station, at which said projection system can image said mask portion onto said substrate, and a measurement station; characterized in that

said second object table has a physical reference surface fixed thereto;

and by:

height mapping means located at said measurement station and constructed and arranged to measure the height, relative to said physical reference surface, of a plurality of points on the surface of a substrate held on said substrate holder and to create a height map thereof;

position measuring means located at said exposure station for measuring the position of said physical reference surface in a first direction substantially perpendicular to said substrate surface, after movement of said second object table to said exposure station; and

control means constructed and arranged to control the position of said second object table in at least said first direction, during exposure of said target portion, in accordance with said height map and said position measured by said position measuring means.

According to a further aspect of the present invention there is provided a method of manufacturing a device using a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a mask holder for holding a mask;

a second, movable object table provided with a substrate holder for holding a substrate; and

a projection system for imaging irradiated portions of the mask onto target portions of the substrate at an exposure station; the method comprising the steps of:

providing a mask bearing a pattern to said first object table;

providing a substrate having a radiation-sensitive layer to said second object table; and

imaging said irradiated portions of the mask onto said target portions of the substrate; characterized by the steps of:

before said step of imaging, generating, with the second object table at a measurement station, a height map indicating the height of a plurality of points on the substrate surface relative to a physical reference surface on said second object table;

moving the second object table to said exposure station and measuring the position of said physical reference surface in a first direction substantially perpendicular to said substrate surface; and

during said step of imaging, positioning the second object table in at least said first direction by reference to said height map and said measured position in said first direction of said physical reference surface.

In a manufacturing process using a lithographic projection apparatus according to the invention a pattern in a mask is imaged onto a substrate which is at least partially covered by a layer of energy-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallisation, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices (dies) will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "exposure area", respectively.

In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation or particle flux, including, but not limited to, ultraviolet radiation (e.g. at a wavelength of 365nm, 248nm, 193nm, 157nm or 126nm), extreme ultraviolet radiation (EUV), X-rays, electrons and ions. Also herein, the invention is described using a reference system of orthogonal X, Y and Z

directions and rotation about an axis parallel to the *I* direction is denoted R*i*. Further, unless the context otherwise requires, the term "vertical" (Z) used herein is intended to refer to the direction normal to the substrate or mask surface, rather than implying any particular orientation of the apparatus.

Embodiment 1

Figure 1 schematically depicts a lithographic projection apparatus according to the invention. The apparatus comprises:

- a radiation system LA, Ex, IN, CO for supplying a projection beam PB of radiation (e.g. UV or EUV radiation);
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a second object table (substrate or wafer table) WTa provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a third object table (substrate or wafer table) WTb provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to third positioning means for accurately positioning the substrate with respect to item PL;
- a measurement system MS for performing measurement (characterization) processes on a substrate held on a substrate table WTa or WTb at a measurement station;

- a projection system ("lens") PL (e.g. a refractive or catadioptric system, a mirror group or an array of field deflectors) for imaging an irradiated portion of the mask MA onto an exposure area C (die) of a substrate W held in a substrate table WTa or WTb at an exposure station.

As here depicted, the apparatus is of a transmissive type (i.e. has a transmissive mask). However, in general, it may also be of a reflective type, for example.

The radiation system comprises a source LA (e.g. a Hg lamp, examiner laser, an undulator provided around the path of an electron beam in a storage ring or synchrotron, a laser plasma source or an electron or ion beam source) which produces a beam of radiation. This beam is passed along various optical components comprised in the illumination system, — e.g. beam shaping optics Ex, an integrator IN and a condenser CO — so that the resultant beam PB has a desired shape and intensity distribution in its cross-section.

The beam PB subsequently intercepts the mask MA which is held in a mask holder on a mask table MT. Having passed through the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto an exposure area C of the substrate W. With the aid of the interferometric displacement and measuring means IF, the substrate tables WTa, WTb can be moved accurately by the second and third positioning means, e.g. so as to position different exposure areas C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library. In general, movement of the object tables MT, WTa, WTb will be realized with the aid of a long stroke module (course positioning) and a short stroke module (fine positioning), which are not explicitly depicted in Figure 1. In the case of a waferstepper (as opposed to a step-and-scan apparatus) the reticle table may be connected only to a short stroke positioning device, to make fine adjustments in mask orientation and position.

The second and third positioning means may be constructed so as to be able to position their respective substrate tables WTa, WTb over a range encompassing both the exposure station under projection system PL and the measurement station under the measurement system MS. Alternatively, the second and third positioning means may be replaced by separate exposure station and measurement station positioning systems for

positioning a substrate table in the respective exposure stations and a table exchange means for exchanging the substrate tables between the two positioning systems. Suitable positioning systems are described, inter alia, in WO 98/28665 and WO 98/40791 mentioned above. It should be noted that a lithography apparatus may have multiple exposure stations and/or multiple measurement stations and that the numbers of measurement and exposure stations may be different than each other and the total number of stations need not equal the number of substrate tables. Indeed, the principle of separate exposure and measurement stations may be employed even with a single substrate table.

The depicted apparatus can be used in two different modes:

1. In step-and-repeat (step) mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (i.e. a single "flash") onto an exposure area C. The substrate table WT is then shifted in the X and/or Y directions so that a different exposure area C can be irradiated by the beam PB;

2. In step-and-scan (scan) mode, essentially the same scenario applies, except that a given exposure area C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the Y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WTa or WTb is moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large exposure area C can be exposed, without having to compromise on resolution.

An important factor influencing the imaging quality of a lithographic apparatus is the accuracy with which the mask image is focused on the substrate. In practice, since the scope for adjusting the position of the focal plane of the projection system PL is limited and the depth of focus of that system is small, this means that the exposure area of the wafer (substrate) must be positioned precisely in the focal plane of the projection system PL. To do this, it is of course necessary to know both the position of the focal plane of the projection system PL and the position of the top surface of the wafer. Wafers are polished to a very high degree of flatness but nevertheless deviation of the

wafer surface from perfect flatness (referred to as "unflatness") of sufficient magnitude noticeably to affect focus accuracy can occur. Unflatness may be caused, for example, by variations in wafer thickness, distortion of the shape of the wafer or contaminants on the wafer holder. The presence of structures due to previous process steps also significantly affects the wafer height (flatness). In the present invention, the cause of unflatness is largely irrelevant; only the height of the top surface of the wafer is considered. Unless the context otherwise requires, references below to "the wafer surface" refer to the top surface of the wafer onto which will be projected the mask image.

According to the invention, after loading a wafer onto the substrate table, the height of the wafer surface Z_{Wafer} relative to a physical reference surface of the substrate table is mapped. This process is carried out at the measurement station using a first sensor, referred to as the level sensor, which measures the vertical (Z) position of the physical reference surface and the vertical position of the wafer surface, Z_{LS}, at a plurality of points, and a second sensor, for example a Z-interferometer, which simultaneously measures the vertical position of the substrate table, Z_{IF} at the same points. As shown in Figure 2, the wafer surface height is determined as $Z_{Wafer} = Z_{LS} - Z_{IF}$. The substrate table carrying the wafer is then transferred to the exposure station and the vertical position of the physical reference surface is again determined. The height map is then referred to in positioning the wafer at the correct vertical position during the exposure process. This procedure is described in more detail below with reference to Figures 3 to 6.

As shown in Figure 3, first the substrate table is moved so that a physical reference surface fixed to the substrate table is underneath the level sensor LS. The physical reference surface may be any convenient surface whose position in X, Y and Z on the substrate table will not change during processing of a wafer in the lithographic apparatus and, most importantly, in the transfer of the substrate table between measurement and exposure stations. The physical reference surface may be part of a fiducial containing other alignment markers and should have such properties as allow its vertical position to be measured by the same sensor as measures the vertical position of the wafer surface. In a presently preferred embodiment the physical reference surface is a reflective surface in a fiducial in which is inset a so-called transmission image sensor (TIS). The TIS is described further below.

The level sensor may be, for example, an optical sensor such as that described in US 5,191,200 (P-0039) (referred to therein as a focus error detection system); alternatively, a pneumatic or capacitive sensor (for example) is conceivable. A presently preferred form of sensor making use of Moiré patterns formed between the image of a projection grating reflected by the wafer surface and a fixed detection grating is described below in relation to a second embodiment of the invention. The level sensor may measure the vertical position of a plurality of positions simultaneously and for each may measure the average height of a small area, so averaging out unflatnesses of high spatial frequencies.

Simultaneously with the measurement of the vertical position of a physical reference surface by the level sensor LS, the vertical position of the substrate table is measured using the Z-interferometer, Z_{IF}. The Z-interferometer may, for example, be part of a three, five or six-axis interferometric metrology system such as that described in WO 99/28790 (P-0077) or WO 99/32940 (P-0079). The Z-interferometer system preferably measures the vertical position of the substrate table at a point having the same position in the XY plane as the calibrated measurement position of the level sensor LS. This may be done by measuring the vertical position of two opposite sides of the substrate table WT at points in line with the measurement position of the level sensor and interpolating/modelling between them. This ensures that, in the event that the wafer table is tilted out of the XY plane, the Z-interferometer measurement correctly indicates the vertical position of the substrate table under the level sensor.

Preferably, this process is repeated with at least a second physical reference surface spaced apart, e.g. diagonally, from the first physical reference surface. Height measurements from two or more positions can then be used to define a reference plane.

The simultaneous measurement of the vertical position of one or more physical reference surfaces and the vertical position of the substrate table establishes a point or points determining the reference plane relative to which the wafer height is to be mapped. A Z-interferometer of the type mentioned above is effectively a displacement sensor rather than an absolute sensor, and so requires zeroing, but provides a highly linear position measurement over a wide range. On the other hand, suitable level sensors, e.g. those mentioned above, may provide an absolute position measurement with respect to an externally defined reference plane (i.e. nominal zero) but over a

smaller range. Where such sensors are used, it is convenient to move the substrate table vertically under the level sensor until the physical reference surface(s) is (are) positioned at a nominal zero in the middle of the measurement range of the level sensor and to read out the current interferometer Z value. One or more of these measurements on physical reference surfaces will establish the reference plane for the height mapping. The Z-interferometer is then zeroed with reference to the reference plane. In this way the reference plane is related to the physical surface on the substrate table and the Z_{Wafer} height map is made independent of the initial zero position of the Z-interferometer at the measurement station and other local factors such as any unflatness in the base plate over which the substrate table is moved. Additionally, the height map is made independent of any drift in the zero position of the level sensor.

As illustrated in Figure 4, once the reference plane has been established, the substrate table is moved so that the wafer surface is scanned underneath the level sensor to make the height map. The vertical position of the wafer surface and the vertical position of the substrate table are measured at a plurality of points of known XY position and subtracted from each other to give the wafer height at the known XY positions. These wafer height values form the wafer height map which can be recorded in any suitable form. For example, the wafer height values and XY coordinates may be stored together in so-called indivisible pairs. Alternatively, the points at which wafer height values are taken may be predetermined, e.g. by scanning the wafer along a predetermined path at a predetermined speed and making measurements at predetermined intervals, so that a simple list or array of height values (optionally together with a small number of parameters defining the measurement pattern and/or a starting point) may suffice to define the height map.

The motion of the substrate table during the height mapping scan is largely only in the XY plane. However, if the level sensor LS is of a type which only gives a reliable zero reading, the substrate table is also moved vertically to keep the wafer surface at the zero position of the level sensor. The wafer height is then essentially derived from the Z movements of the substrate table, as measured by the Z-interferometer, necessary to maintain a zero readout from the level sensor. However, it is preferable to use a level sensor that has an appreciable measurement range over which its output is linearly related to wafer height, or can be linearized. Such measurement

range ideally encompasses the maximum expected, or permissible, variation in wafer height. With such a sensor, the need for vertical movement of the substrate table during the scan is reduced or eliminated and the scan can be completed faster, since the scan speed is then limited by the sensor response time rather than by the ability of the short stroke substrate table to track the contour of the wafer in three dimensions. Also, a sensor with an appreciable linear range can allow the heights at a plurality of positions (e.g. an array of spots) to be measured simultaneously.

Next, the wafer table is moved to the exposure station and, as shown in Figure 5, the (physical) reference surface is positioned under the projection lens so as to allow a measurement of its vertical position relative to the focal plane of the projection lens. In a preferred embodiment, this is achieved using one or more transmission image sensors (described below) whose detector is physically connected to the reference surface used in the earlier measurements. The transmission image sensor(s) can determine the vertical focus position of the projected image from the mask under the projection lens. Armed with this measurement, the reference plane can be related to the focal plane of the projection lens and a path for the substrate table in three-dimensions which keeps the wafer surface in optimum focus can be determined. One method by which this can be done is to calculate Z, Rx and Ry setpoints for a series of points along the scan path. The setpoints are determined using a least squares method so as to minimize the difference between the wafer map data and the focus plane of the exposure slit image. For ease of calculation, the relative motion of the exposure slit image and wafer can be expressed as the slit moving relative to a static wafer. The least squares criterion can then be expressed as, for each time t, finding the values $Z(t)$, $Rx(t)$ and $Ry(t)$ which give a minimum value of:

$$LSQ(t) = \frac{1}{s}\cdot\frac{1}{W}\int_{-s/2}^{s/2}\int_{-W/2}^{W/2}\left[w(x,y) - (Z(t) + x.Ry(t) - y.Rx(t))\right]^2 dx dy \qquad [1]$$

where $w(x,y)$ is the wafer height map and the exposure slit image is a rectangular plane of width s in the scanning direction and length W perpendicular to the scanning direction with its position defined by $z(t)$, $Rx(t)$ and $Ry(t)$. The setpoints and the wafer trajectory can be expressed as functions of either Y (position in the scanning direction)

or t (time) since these are related by $Y = y_0+v.t$, where y_0 is the starting position and v is the scanning speed.

As mentioned above, the physical reference surface(s) is (are) preferably a surface in which a transmission image sensor (TIS) is inset. As shown in Figure 7, two sensors TIS1 and TIS2 are mounted on a fiducial plate mounted to the top surface of the substrate table (WT, WTa or WTb), at diagonally opposite positions outside the area covered by the wafer W. The fiducial plate is made of a highly stable material with a very low coefficient of thermal expansion, e.g. Invar, and has a flat reflective upper surface which may carry markers used in alignment processes. TIS1 and TIS2 are sensors used to determine directly the vertical (and horizontal) position of the aerial image of the projection lens. They comprise apertures in the respective surface close behind which is placed a photodetector sensitive to the radiation used for the exposure process. To determine the position of the focal plane, the projection lens projects into space an image of a TIS pattern TIS-M provided on the mask MA and having contrasting light and dark regions. The substrate stage is then scanned horizontally (in one or preferably two directions) and vertically so that the aperture of the TIS passes through the space where the aerial image is expected to be. As the TIS aperture passes through the light and dark portions of the image of the TIS pattern, the output of the photodetector will fluctuate. The vertical level at which the rate of change of amplitude of the photodetector output is highest indicates the level at which the image of TIS pattern has the greatest contrast and hence indicates the plane of optimum focus. An example of a TIS of this type is described in greater detail in US 4,540,277. Instead of the TIS, a Reflection Image Sensor (RIS) such as that described in US 5,144,363 may also be used.

Using the surface of the TIS as the physical reference surface has the advantage that the TIS measurement directly relates the reference plane used for the height map to the focal plane of the projection lens and so the height map can be employed directly to give height corrections for the wafer stage during the exposure process. This is illustrated in Figure 6, which shows the substrate table WT as positioned under the control of the Z-interferometer at a height determined by the height map so that the wafer surface is at the correct position under the projection lens PL.

The TIS surface may additionally carry reference markers whose position is detected using a through-the-lens (TTL) alignment system to align the substrate table to the mask. Such an alignment system is described in EP-0,467,445 A (P-0032), for example. Alignment of individual exposure areas can also be carried out, or may be obviated by an alignment procedure carried out at the measurement stage to align the exposure areas to the reference markers on the wafer stage. Such a procedure is described in EP-0 906 590 A (P-0070) for example.

It will be appreciated that the mask image projected by the projection system PL in a production process, in both step-and-repeat and step-and-scan modes, is not a single point but extends over a significant area in the XY plane. Since the wafer height may vary significantly over this area it is desirable to optimize the focus over the whole of the projection area, rather than just at a single point. In embodiments of the present invention, this can be achieved by controlling not only the vertical position of the substrate table WT, but also its tilt about the X and Y axes (Rx, Ry). With knowledge of the location and extent of the intended exposure areas, the height map generated by the present invention can be used to calculate in advance optimum Z, Rx and Ry position setpoints for the substrate table for each exposure. This avoids the time required for levelling in known apparatus that only measure wafer height when the wafer is positioned under the projection lens and hence increases throughput. The optimum Z, Rx and Ry setpoints may be calculated by various known mathematical techniques, for example using an iterative process to minimize defocus (defined as the distance between the wafer surface and the ideal focal plane), *LSQ (t)*, integrated over the exposure area.

A further advantage is possible in the step-and-scan mode. In this mode, the projection lens projects an image of only part of the mask pattern onto a corresponding part of the exposure area. The mask and substrate are then scanned in synchronism through the object and image focal planes of the projection system PL so that the entire mask pattern is imaged onto the whole exposure area. Although in practice the projection lens is held stationary and the mask and substrate are moved, it is often convenient to consider this process in terms of an image slit moving over the wafer surface. With the height map determined in advance by the present invention, it is possible to calculate a sequence of Z, Rx and Ry setpoints matched to the XY scan path

(usually, scanning takes place in only one direction, e.g. Y). The sequence of setpoints can be optimized according to additional criteria, e.g. to minimize vertical accelerations or tilt motions that might reduce throughput or induce undesirable vibrations. Given a sequence of spaced-apart setpoints, a scanning trajectory for the exposure can be calculated using a polynomial or spline fitting procedure.

Whilst the present invention aims to position the wafer at the optimum position in Z, Rx and Ry for a given exposure, the variations in wafer surface height over the exposure area may be such that the wafer cannot be positioned to give adequate focus over the entire area. Such so-called focus spots can result in an exposure failure. However, with the present invention such failures can be predicted in advance and remedial action can be taken. For example, the wafer may be stripped and recoated without the detrimental effect of further processing a badly exposed wafer. Alternatively, if the predicted failure affects only one or a few devices on the wafer whilst others will be acceptable, throughput may be enhanced by skipping exposures that can be predicted in advance to result in defective devices.

A further advantage of focus-spot detection can be derived from analysis of height maps taken. When large deviations from a global wafer plane are present in a wafer height map, this could indicate focus spots due to substrate unflatness or process influences. Comparing wafer height maps from several wafers can indicate focus spots due to contamination or unflatness of the substrate table. When focus spots appear at identical or near-identical positions for different wafers, this is most likely caused by substrate holder contamination (so-called "chuck-spots"). From one wafer height map, one can also compare the height map (topology) from repeated exposure areas (dies). If large differences occur at certain dies with respect to an average height map, one can suspect focus spots due to either wafer processing or the substrate table. Instead of comparing wafer height maps, the same comparisons can also be done on the derived exposure paths per die, or on the defocus parameters MA, MSD or Moving Focus explained below. When a certain die or wafer deviates much from an average exposure path or defocus parameters, focus spots can also be detected.

All of the above mentioned analysis can be done before a wafer is exposed, and remedial action, such as wafer rejection (processing influences) or substrate holder cleaning (chuck spots), can be taken. With these methods, focus spots can be localised to

the size of the measurement spot of the level sensor 10. This implies a much higher resolution than previous methods of focus spot detection.

Embodiment 2

A second embodiment of the present invention is shown in Figure 8, which shows only the exposure and measurement stations and only components relevant to the discussion below. The second embodiment utilizes the levelling principle of the present invention described above, together with certain refinements described below.

At the exposure station, to the left of Figure 8, the projection lens PL is shown mounted to metrology frame MF and projecting an image of TIS marker TIS-M on mask MA onto the sensor TIS mounted to wafer table WT. The metrology frame is isolated from the transmission of vibrations from other parts of the apparatus and has mounted on it only passive components used for fine metrology and alignment sensing. The whole metrology frame may be made of a material with a very low coefficient of thermal expansion, such as Invar, so that it provides a very stable platform for the most sensitive measuring devices of the apparatus. The components mounted on the metrology frame MF include mirrors 34 and 35 to which the measurement beams of the Z-interferometer Z_{IF} are directed by 45°-mirrors 31 mounted on the sides of the wafer table WT. To ensure that the Z position of the substrate table can be measured throughout its range of movement in X, the mirrors 34, 35 have a correspondingly large extent in the X direction. To ensure the Z position can be measured throughout the range of Y-movement, the mirrors 31 cover the whole length of the wafer table. Also mounted to the metrology frame MF are the beam generating and receiving parts 21a, 22a of a confidence sensor 20a described further below.

At the measurement station(on the right in Figure 8), the same metrology frame MF carries mirrors 33 and 32 which serve the same function as the mirrors 34, 35 at the exposure station; again mirrors 32, 33 will have a large extent in the X direction to accommodate the required range of movement of the substrate table WT which is just as large as that at the exposure station. Level sensor 10, comprising beam generating part 11 and detection part 12, is also mounted on the metrology frame MF. Additionally, a confidence sensor 20b, essentially the same as confidence sensor 20a at the exposure

position, is provided. Other measurement devices, for example an alignment module, can also be provided.

As discussed above, the use of the physical reference surface (again in this embodiment this is provided by the upper surface of the TIS) relates the wafer height map to the wafer stage and makes it independent of the zero positions of the two Z-interferometers and certain local factors such as unflatness of the base plate (stone) BP over which the wafer tables move. However, since the wafer height map is generated using the Z-interferometer at the measurement station and the substrate table position is controlled at the exposure station using a different Z-interferometer provided there, any differences as a function of XY position between the two Z-interferometers can affect the accuracy with which the wafer surface is positioned in the focal plane. The principal cause of these variations in an interferometer system of the type used in the present invention is unflatness of the mirrors 32, 33, 34, 35. The 45° mirrors 31 are attached to the wafer table WT and travel with it as it swaps between exposure and measurement stations. Any unflatness of these mirrors therefore has largely the same effect on positioning at the exposure station as at the measurement station, and largely cancels out. However, the mirrors 32, 33, 34 and 35 mounted on the metrology frame MF stay with their respective interferometers and so any differences in the surface contours of the corresponding pairs 32, 34 and 33, 35 can adversely affect the vertical positioning accuracy of the substrate table WT.

The confidence sensors 20a and 20b are used at initial set-up of the apparatus, and periodically as required thereafter, to calibrate the differences between the Z-interferometers at the measurement and exposure stations. The confidence sensors are sensors capable of measuring the vertical position of the upper surface of the wafer at one or more points as the substrate table is scanned underneath it. Confidence sensors 20a and 20b can be similar in design to level sensor 10 but need not be; since they are used only at setup (and for infrequent recalibration) and with a reference wafer rather than production wafers, the design criteria are less onerous and advantage can be taken of this to design a simpler sensor. Conversely, the existence of the projection lens PL at the exposure station will restrict the physical locations available for the confidence sensor at that station, and this also needs to be taken into account in design or selection

of each confidence sensor. High accuracy is required of the confidence sensors since the calibration they are used for will affect the quality of every exposure.

In the calibration process using the confidence sensor(s), a reference wafer is loaded onto the substrate table. The reference wafer is preferably a bare silicon wafer. There is no requirement for it to be any flatter than a normal bare Si wafer but its surface finish (in terms of reflectivity) is preferably optimized for the confidence sensors. In a preferred embodiment of the invention the reference wafer is preferably polished to maximize its reflectivity and minimize unflatness.

In the calibration procedure, a partial height map of the reference wafer (as usual referenced to the physical reference surface) is generated at the measurement station using the confidence sensor 20b instead of the level sensor 10. This is done in the same manner as with the level sensor 10: the physical reference surface (TIS) is positioned at the zero point of the confidence sensor to zero the Z-interferometer, the wafer is then scanned under the confidence sensor, and the height map is generated from the difference between the confidence sensor and Z-interferometer readings. A height map is also generated at the exposure station using the confidence sensor 20a at the same points as the measurement station height map. For this calibration, the height maps need not be a complete scan of the wafer; they need only cover strips corresponding to the movement of the Z-interferometer beam over the mirrors 32-35. (The order in which the maps are created is not important, provided the wafer is stable on the substrate table whilst both are done.)

Since the height maps represent the same wafer, any differences between them will be caused by differences between the measurement systems used to create them. The two confidence sensors are static, so their effects on the height maps will not be position-dependent and can be eliminated by normalizing the two height maps and/or subtracting static offsets. Any remaining differences will be position-dependent, and the two height maps can be subtracted from one another to generate correction tables (mirror maps) that relates the exposure station Z-interferometer to the measurement station Z-interferometer. These correction tables can be attributed to the differences between the mirrors 33, 35 and 32, 34 attached to the metrology frame MF and can be applied to the wafer height maps generated in a production process, or used to correct one of the Z-interferometers used to generate the map or to position the substrate table

during the exposure. Depending on the precise construction of the Z-interferometers, particularly the metrology frame mirrors and substrate table mirrors, the differences in Z position caused by the unflatnesses of the mirrors in each interferometer system may also be tilt dependent in one or more degrees of freedom (Rx, Ry, Rz). To eliminate this tilt dependence it may be necessary to use the confidence sensors to create several height maps with the wafer stage at various different tilts, from which a number of different correction tables (mirror maps) can be derived, as necessary.

Having described the principle of the off-axis levelling procedure, now will be described some further refinements to it that are employed in the second embodiment, as well as how it is integrated into the production process. Figures 9 and 10 are referred to and respectively show the steps carried out at the measurement station and at the exposure station. In a lithography apparatus using two wafer tables, one table will be going through the steps of Figure 9 whilst a second simultaneously goes through the steps of Figure 10 before they are swapped. In the description below, the "life" of a single wafer is followed from measurement station (Figure 9) to exposure station (Figure 10) and back.

Starting at step S1 in Figure 9, a wafer coated with a photosensitive resist is loaded on to the substrate table WT. (Note that this may generally take place at a loading station separate from the measurement station at which the substrate table is out of range of the interferometer system IF.) The wafer table is moved into the capture range(s) of one or more position sensitive devices (PSDs) so that an initial coarse zeroing of the interferometric metrology system can be performed, step S2. After the initial coarse zeroing, the fine initialization/zeroing of the interferometric system follows in steps S3 and S4. These two steps contain the level sensor measurements (denoted "LS") on the (two or more) physical reference surfaces, which will define the reference plane (fixed to the wafer table) with respect to which the wafer height map is measured. Also, two alignment measurements (denoted "AA") are done on markers located on the same physical reference surfaces, so as to define the horizontal reference positions fixed to the wafer table. These measurements in S3 and S4 effectively zero the interferometric system in all degrees of freedom.

The next step in the levelling procedure is step S5, referred to as the global level contour (GLC). In this step, which is described further below, a wafer capture and an

initial scan of the wafer with the level sensor is made to determine its overall height and tilt as well as its approximate height at the points where the subsequent detailed scan will move onto or off the wafer. This information enables the substrate table trajectory for the wafer height map scan to be defined.

In step S6, a global alignment of the wafer is done. At least two alignment markers on the wafer are measured (W1 and W2), meaning that their XY position is determined with respect to the reference markers on the TIS fiducials. This determines to what extent the wafer is horizontally rotated (Rz) with respect to the scan direction (y), and is done to be able to correct the wafer rotation such that the wafer height map scans are done parallel to the exposure area axis (i.e. "going straight over the exposure areas").

After that, the levelling procedure continues with measurements necessary for a process dependent correction (PDC). A process dependent correction is necessary with some forms of level sensor, and will now be explained.

The wafer height map must be taken each time a wafer is exposed. If a wafer has already been subjected to one or more process steps, the surface layer will no longer be pure polished silicon and there may also be structures or topology representing the features already created on the wafer. Different surface layers and structures can affect the level sensor readings and in particular can alter its linearity. If the level sensor is optical, these effects may, for example, be due to diffraction effects caused by the surface structure or by wavelength dependence in the surface reflectivity, and cannot always be predicted. To determine the required process dependent correction, an exposure area or die is scanned under the level sensor with the substrate table WT set to several different vertical positions spanning the linear or linearized range of the level sensor 10. The wafer height, i.e. the physical distance between the wafer surface and the reference plane, should not change with the vertical position of the substrate table; it is obtained by subtracting the measurements of the level sensor and Z-interferometer: $Z_{WAFER} = Z_{LS} - Z_{IF}$. Therefore if the determined value of Z_{WAFER} does change with vertical position of the substrate table this indicates that either or both the level sensor or Z-interferometer are not linear or not equally scaled. The Z-interferometer is deemed to be linear since it looks at the mirrors on the wafer table and metrology frame; and in fact is linear to a greater extent than the required accuracy for the wafer height map, at least once the

correction determined by the use of the confidence sensor is applied. Therefore, any differences in the wafer height values are assumed to result from non-linearity or mis-scaling of the level sensor. They, and the knowledge of at which level sensor readings they were observed, can be used to correct the output of the level sensor. It has been found in a presently preferred embodiment of the level sensor that a simple gain correction is sufficient, but a more complex correction may be required for other sensors.

If the wafer to be processed has exposure areas on it that have been subjected to different processes, then a process-dependent correction is determined for each different type of exposure area on the wafer. Conversely, if a batch of wafers having exposure areas that have undergone the same or similar processes are to be exposed, it may only be necessary to measure the process-dependent correction for each type of exposure area once per batch. That correction can then be applied each time that type of exposure area is height-mapped in the batch.

In many IC fabs, the photosensitive resist is applied to the wafer immediately before it is loaded into the lithography apparatus. For this, and other, reasons, the wafer may be at a different temperature than the substrate table when it is loaded and clamped in place. When the wafer cools (or warms) to the same temperature as the substrate table, thermal stresses can be set up because the wafer is clamped very rigidly using vacuum suction. These may result in undesirable distortion of the wafer. Thermal equilibrium is likely to have been reached by the time the steps S2 to S7 have been completed. Therefore, at step S8, the vacuum clamping the wafer to the substrate table is released, to allow the thermal stresses in the wafer to relax, and then reapplied. This relaxation may cause small shifts in the position and/or tilt of the wafer but these are acceptable since steps S2 to S4 are independent of the wafer and S5 and S6 are only coarse measurements. Any shift in the wafer position at this stage does not affect the process-dependent correction since that is a calibration of the level sensor rather than a measurement of the wafer.

After the vacuum has been reapplied, and from here on it is not released again until the exposure process is finished, the Z-map is carried out at step S9. The scan required for the Z-map must measure the height of sufficient points to enable the wafer to be positioned during exposure at the desired accuracy. It is also important that the

points measured cover the actual area where the wafer is to be exposed; measurements taken over non-exposure areas, such as scribe lanes and so-called mouse bites, may give misleading results. Accordingly, the height mapping scan must be optimized to the specific pattern of exposure areas on the wafer at hand; this is described further below.

Once the Z-map is completed, the advance alignment measurements, step S10, are carried out before the substrate table is swapped, at step S11, to the exposure position. In the advance alignment process, the positions of a number of alignment markers on the wafer relative to the reference markers F located on the TIS fiducial (physical reference surface) fixed to the substrate table are accurately determined. This process is not particularly relevant to the present invention and so is not described further herein.

In the swap procedure, the substrate table carrying the height-mapped wafer arrives at the exposure station, step S13 in Figure 10. A coarse position determination of the substrate table is made at step S14 and, if necessary, a new mask MA is loaded onto the mask table MT, step S15. The mask loading process may be carried out, or at least begun, simultaneously with the substrate table swap. Once a mask is in position and a coarse position determination, step S14, has been made, a first TIS scan is carried out using sensor TIS1 at step S16. The TIS scan measures the vertical and horizontal position of the substrate table at which the TIS is located in the aerial image focus of the projection lens, as described above, yielding a focal plane reference. Since the height map generated as step S9 in Figure 9 is referenced to the physical surface in which the TIS is located, the vertical positions of the substrate table necessary to put the wafer surface in the focal plane for the different exposure areas are directly derived. A second TIS scan, step S17, is also carried out using sensor TIS2, yielding a second point for referencing a focal plane.

Once the TIS scans have been completed and the focal plane determined, the exposure process S18 is carried out, optionally after any necessary system calibrations in step S19 (e.g. adjustments to correct for lens heating effects). The exposure process will generally involve the exposure of multiple exposure areas using one or more masks. Where multiple masks are used, after mask exchange S20, one TIS scan S17 can be repeated to update any focal plane changes. Between some or all exposures, the system calibration step S19 may also be repeated. After completion of all exposures, the

substrate table carrying the exposed wafer is swapped at step S13 for the substrate table carrying the wafer that has meanwhile been undergoing steps S1 to S10 of Figure 9. The substrate table carrying the exposed wafer is moved to the loading station and the exposed wafer taken out so that a fresh wafer can be loaded and the cycle can resume.

To explain the wafer height mapping scan of step S9 of Figure 9, Figure 11 shows an example of a pattern of exposure areas C of various shapes and sizes arranged on a wafer to make best use of the silicon area. The different exposure areas C are separated by scribe lanes SL and generally-triangular unused areas, known as "mouse-bites" are inevitably left between the rectangular exposure areas and the curved edge of the wafer. The scribe lanes are where the wafer will be cut once all production processes have been completed (so as to separate the different devices) and some cutting techniques may require that the scribe lanes in one direction all span the entire width of the wafer; in that case it is convenient to orient these full wafer-width scribe lanes parallel to the scanning direction (e.g. the Y direction) if the apparatus is to be used in step-and-scan mode. The scribe lanes and mouse bites may not be exposed, and so after the wafer has been subjected to a few process steps or depositions of layers they may have very different heights and surface properties than the exposure areas C. Accordingly it is important to disregard any height measurements in these areas, which are not going to be exposed.

A presently preferred embodiment of the level sensor uses a linear array of, e.g., nine optical spots arranged perpendicular to the scanning direction to measure the height at nine points (areas) simultaneously. (Note that the Z-interferometer data can also be interpolated to provide corresponding Z-position data of the substrate table at an array of corresponding level sensor points.) The array of spots is of a size sufficient to cover the width of the widest exposure area that can be exposed in the apparatus.

The presently preferred scanning scheme is to scan the array of spots in a meander path 50 such that the center spot of the array passes along the midline of each column of exposure areas; this midline corresponds to the midline of the illuminated slit in the exposure process. The data thus generated can be directly related to the exposure scan with a minimum of rearrangement or calculation. This method also eliminates part of the mirror unflatness effect, since, at both measurement and exposure stations, scans are carried out with the Z-interferometer beam pointing at the same position on the

mirrors 31 attached to the substrate table. If the column of dies is narrower than the array of spots of the level sensor, data obtained from the spots not lying wholly within the exposure area are ignored. In other embodiments of the level sensor it may be possible to adjust the width of the array of spots to match the width of the exposure areas.

If a wafer has some exposure areas whose center lines are offset in the direction perpendicular to the scanning direction from those of the remainder, a modified scanning scheme may be used to advantage. This situation is illustrated in Figure 12 which shows one row of dies E whose center lines are offset from the remaining dies D. In such a case, the map can be created more quickly and with fewer accelerations for the substrate table by scanning two meander paths. One path, referenced 52 in Figure 12, covers one set of exposure areas D and the other, referenced 53, covers the others E. Of course, other arrangements of the exposure areas may require further modifications to the scanning scheme.

Where the level sensor has a limited linear or linearized range, which is likely the case, the substrate table WT must be scanned underneath it at a vertical position that brings the wafer surface into that range. Once the wafer surface has been found it is a simple matter, by means of a closed feedback loop of the level sensor reading to the substrate table positioning system, to adjust the vertical position of the substrate table WT to keep the wafer surface in the linear or linearized range but it is not so simple to find the wafer surface when the level sensor first moves onto an exposure area from outside the wafer. In a meander path there are several such in-points, referenced 51 and indicated by arrows on the meander path 50 in Figure 11, compounding the problem.

To find the wafer surface at the in-points 51 it is possible to provide a capture spot in advance of the main level sensor spot array. The reflection of the capture spot on the wafer is then directed to a detector that has a wider capture range than is the case for the main spots. This, however, requires additional hardware: a capture spot on both sides of the main spots (before/after) or a restriction to scanning in only one direction. An alternative, not necessarily requiring additional hardware, is to stop the substrate table close to each in-point, perform a wafer capture and measure the wafer surface in the linear or linearized range of the level sensor to approximate the wafer surface

position at the in-point. This however slows down the measurement procedure significantly, which may have undesirable consequences for throughput.

In this embodiment of the invention, these problems are avoided by performing a global level contour scan mentioned above (step S5 in Figure 9) after the wafer surface is captured. The global level contour scan is explained further with reference to Figure 13.

For the global level contour scan the substrate table is first positioned so that a convenient point (preferably near the edge) within an exposure area C is underneath a single capture spot and the main spots of the level sensor (spot array). The wafer surface is found, e.g. by scanning the substrate table vertically until the wafer surface is captured and comes within the linear or linearized range of the main spots, and then the substrate table is scanned so that the central spot 41 traverses a path 60 around the inside of the perimeter of the total exposure area. The capture procedure is described further below. Measurements of the wafer surface height are taken at defined positions around the scan. Where other spots of the array as well as the center spot fall over (exposure areas of) the wafer, the measurements from these spots, as well as the central one, can also be taken. However, measurements should not be taken from spots falling outside the exposure areas. As illustrated, the global level contour path 60 is a winding path following the edges of the exposure areas quite closely; however a smoother path may also be employed and, particularly when the wafer is well filled with exposure areas, a circular course 61 may well suffice and be more convenient. The global level contour may also be arranged as a circle passing over mouse bites, in which case measurements are not taken over the mouse bites, or the data of any measurements taken on mouse bites are disregarded in calculation of the global height and tilt of the wafer.

The data gathered in the global level contour scan are used for two purposes. Firstly data relating to the wafer height in the vicinity of the in-points 51 (see Figure 11) of the height mapping scan to be carried out later are used to predict the wafer height at the in-points 51 so that the substrate table can be brought to the correct height to get the wafer surface position in the linear or linearized level sensor range during the mapping scan. In most cases only a few data points are required for this and they need not be particularly close to the in-points to allow a sufficiently accurate prediction of the wafer height to be determined by interpolation or extrapolation. It is also desirable to know

the local Ry tilt at the in-points 51 for the height mapping scan, since the level sensor has an array of spots in the X-direction which (preferably) all need to be brought within their linear or linearized ranges. If the global level contour scan is parallel, or nearly parallel, to the Y direction in the vicinity of any in-point, the Ry tilt cannot be accurately determined using data obtained from only a single spot. Where a level sensor having an array of measurement spots spaced apart in the X direction, such as that described below, is used, data from multiple spots can be used to determine a local Ry tilt. Of course, data from spots lying within the exposure area are selected if part of the array falls outside that area.

The second use of the global level contour data is to determine a global, or average, height and tilt (around 2 axes) for the whole wafer. This is done by known mathematical techniques, e.g. a least-squares method, to determine a plane that most closely fits the wafer height data gathered. If the global tilt (sometimes referred to as the "wedge") is greater than a predetermined amount, this may well indicate an incorrect loading procedure. In that case the wafer can be unloaded and reloaded for a retry and even rejected if it continues to fail. The global height and tilt information is used to focus an advance alignment sensor used in step S10 of Figure 9 to accurately determine the spatial relationship of alignment markers on the wafer to reference markers on the substrate stage. The advance alignment sensor and process are described in greater detail in WO 98/39689 (P-0070).

During a wafermap scan, the level sensor 10 provides continuous Z and Ry feedback signals to the substrate table to keep the level sensor 10 in its linear or linearized range. If this feedback loop stops (the level sensor 10 doesn't supply correct numbers) the table is controlled by following a path corresponding to the global wafer wedge (a Z profile according to global Rx).

A presently preferred embodiment of the level sensor 10 is illustrated in Figure 14 and will be explained below additionally with reference to Figures 14A to 14G, which show aspects of the operation of the sensor.

Level sensor 10 comprises a beam generation branch 11 which directs a measurement beam b_{LS} onto the wafer W (or the physical reference plane when the vertical position of that is being measured, or any reflecting surface) and a detection

branch 12 which measures the position of the reflected beam, which is dependent on the vertical position of the wafer surface.

In the beam generation branch, the measurement beam is generated by light source 111, which may be an array of light emitting or laser diodes, or generated elsewhere and passed to "illuminator" 111 by optical fibers. The beam emitted by light source 111 preferably contains a wide band of wavelengths, e.g. from about 600 to 1050 nm, so as to average out any wavelength dependence of interference effects from the wafer surface, particularly after some process steps have been completed. Illumination optics 112, which may include any suitable combination of lenses and mirrors, collect the light emitted by light source 111 and evenly illuminate projection grating 113. Projection grating 113 is shown in greater detail in Figure 14A and consists of an elongate grating 113a, which may be divided to generate an array of separate/discrete spots, with grating lines parallel to its axis, and an additional aperture 113b which forms a capture spot ahead of the main detection spot array on the wafer. The period of the grating will be determined in part by the accuracy at which the wafer surface position is to be measured and may, for example be about 30μm. The projection grating is positioned with a small rotation around its optical axis such that the grating lines projected on the wafer are not parallel to any wafer coordinate axis, thereby to avoid interference with structures on the wafer which are along the x or y direction. Projection lens 114 is a telecentric system which projects an image of the projection grating 113 onto the wafer W. Projection lens 114 preferably consists essentially or only of reflecting optical elements so as to minimize or avoid chromatic aberration in the projected image; since the projection beam is broadband these cannot easily be eliminated or compensated for in a refractive optical system. Folding mirrors 115, 116 are used to bring the projection beam b_{LS} into and out of the projection lens 114 and permit a convenient arrangement of the components of the beam generation branch.

The projection beam b_{LS} is incident on the wafer at a fairly large angle, α, to the normal, e.g. in the range of from 60° to 80°, and is reflected into the detection branch 12. As shown in Figure 14B, if the wafer surface WS shifts in position by a distance Δh to position WS', then the reflected beam r' will be shifted relative to the beam r, prior to the shift in the wafer surface, by a distance 2.Δh.sin(α). Figure 14B also

shows the appearance of the image on the wafer surface; because of the large angle of incidence, the image is spread out perpendicular to the grating lines.

The reflected beam is collected by detection optics 121 and focused on detection grating 126, which is essentially a copy of projection grating 113 and is sub-divided to correspond to the spot-array pattern. Detection optics 121 are directly complementary to projection optics 114 and will also consist essentially or only of reflective elements, to minimize chromatic aberration. Again folding mirrors 122, 123 may be used to enable a convenient arrangement of the components. Between detection optics 121 and the detection grating 126 are positioned a linear polarizer 124 to polarize the light at 45° and a birefringent crystal 125 which causes a shear perpendicular to the grating lines equal in magnitude to the grating period between the horizontal and vertical polarized components of the light. Figure 14C shows the beam as it would be at the detection grating 126 without the birefringent crystal; it is a series of alternating light and dark bands with the light bands polarized at 45°. The birefringent crystal 125 shifts the horizontal and vertical polarization states so that the light bands of the horizontal polarization component fill the dark bands of the vertical polarization component. As shown in Figure 14D, the illumination at the detection grating 126 is therefore uniform grey but has stripes of alternating polarization state. Figure 14E shows the detection grating 126 overlaid on this pattern, which depends on the vertical position of the wafer surface; when the wafer is at a nominal zero vertical position, the detection grating 126 will overly and block half of the light bands of one polarization state, e.g. the vertical, and half of the other state.

The light passed by the detection grating 126 is collected by modulation optics 127 and focused on detector 128. Modulation optics include an polarization modulation device driven by an alternating signal, e.g. with a frequency of about 50kHz, so as to pass the two polarization states alternately. The image seen by the detector 128 therefore alternates between the two states shown in Figure 14F. Detector 128 is divided into a number of regions corresponding to the array of spots whose height is to be measured. The output of a region of detector 128 is shown in Figure 14G. It is an alternating signal with period equal to that of the modulating optics and the amplitude of the oscillations indicates the degree of alignment of the reflected image of the projection grating on the detection grating, and hence the vertical position of the wafer

surface. As mentioned above, if the wafer surface is at the nominal zero position, the detection grating 126 will block out half of the vertical polarization state and half of the horizontal polarization state so that the measured intensities are equal and the amplitude of the oscillating signals output by the detector regions will be zero. As the vertical position of the wafer surface moves away from the zero position, the detection grating 126 will begin to pass more of the horizontally polarized bands and block more of the vertically polarized bands. The amplitude of the oscillations will then increase. The amplitude of the oscillations, which is a measure of the vertical position of the wafer surface, is not directly linearly related to the vertical position of the wafer surface in nanometers. However, a correction table or formula can readily be determined on initial setup of the apparatus (and periodically recalibrated if necessary) by measuring the constant height of the surface of a bare silicon wafer at various different vertical positions of the substrate table, using the calibrated Z-interferometer and uncalibrated level sensor 10.

To ensure that the measurements of the level sensor and the Z-interferometer are taken simultaneously, a synchronization bus is provided. The synchronization bus carries clock signals of a very stable frequency generated by a master clock of the apparatus. Both the level sensor and Z-interferometer are connected to the synchronization bus and use the clock signals from the bus to determine sampling points of their detectors.

The capture spot 113b passed by the projection grating 113 passes the detection grating, where it is incident on three separate detection regions, two 131, 133 set high and one 132 set low, as shown in Figure 15A. The output from the low detection region is subtracted from those of the high regions. The capture spot detector regions are arranged so that when the wafer surface is at the zero position, the capture spot falls equally on the high and low detection regions and the subtracted output is zero. Away from the zero position, more of the capture spot will fall on one of the detection regions than the other and the subtracted output will increase in magnitude with its sign indicating whether the wafer is too high or too low. The dependence of the subtracted detector output d_{cap} on substrate table position Z_{IF} is illustrated in Figure 15. This form of detector output allows a faster zero capture method than a conventional servo feedback. According to the improved method, referred to as "move-until", when the

capture spot detector indicates that the wafer surface is too high or too low, the Z-position actuators of the substrate table are instructed to move the stage in the appropriate direction to bring the wafer surface into the linear or linearized range of the main level sensor array. The movement of the wafer stage continues until the output of the capture spot detector d_{cs}, passes a trigger level t_h or t_l according to which direction it is traveling. Crossing the trigger level causes the apparatus control to issue a command to the Z-position actuators to begin a braking procedure. The trigger levels are set so that, in the response time and the time taken to brake the stage motion, the stage will move to, or close to, the zero position. Thereafter the stage can be brought to the zero position under control of the more accurate main level sensor spots. The trigger points will be determined in accordance with the dynamics of the stage and need not be symmetrically spaced about zero detector output. This "move-until" control strategy enables a rapid and robust zero capture without requiring a linear measurement system, and can be used in other situations.

The level sensor described above can be further optimized to improve its performance. Improvement in accuracy in the scan (Y) direction can be effected by appropriate signal filtering and this may be adapted to specific process layers observed on partly processed wafers. Additional improvements (for specific process layers) in all directions may be obtained by optimization of the measurement spot geometry, which can be adjusted by changing the illumination optics 112 (to adjust the uniformity and/or angular distribution of the illumination light on the projection grating 113), by changing the projection grating 113 or by adjusting the detection system (size, position and/or angular resolution of the detector and the number of detectors).

A presently preferred form of the confidence sensors 20a, 20b is illustrated in Figures 16 and 17. The beam generation branch 21 comprises a light source 211 (e.g. a solid state laser diode or super-luminescent diode) which emits light of limited bandwidth. It is conveniently situated away from the metrology frame and its output brought to the desired point by an optical fiber 212. The light is output from fiber terminator 213 and directed onto a beam splitter 215 by collimating optics 214. Beam splitter 215 creates two parallel measurement beams b_{a1} and b_{a2} which are focused to evenly illuminate respective spots 23 on the wafer W by telecentric projection optics 216. Since the measurement beams of the confidence sensor have a limited bandwidth,

projection optics 216 can conveniently employ refractive elements. Detection optics 221 collect the reflected beams and focus them at the edge of detection prism 222 which is positioned between detectors 223, 224 and detection optics 221. As shown in Figure 17, which is a side view of detection prism 222 and detector 223, a measurement beam is incident on the back of detection prism 222 and exits through angled faces 222a, 222b. Detector 223 consists of two detector elements 223a, 223b positioned so that light emerging from face 222a of detection prism 222 reaches detector element 223a and that emerging from face 222b reaches detector element 223b. Detector 224 is similar. Outputs of detector elements 223a and 223b are intensity-scaled and subtracted. When the wafer surface is at the zero position, the measurement beam falls symmetrically on faces 222a, 222b of detection prism 222 and equal amounts of light will be directed to detector elements 223a and 223b. These will then give equal outputs and so the subtracted output will be zero. As the wafer surface moves away from the zero position, the position of the reflected beam will move up or down and fall more on one of faces 222a, 222b than on the other resulting in more light being directed to the respective detector element so that the subtracted output will change proportionally. A tilt of the wafer can be determined by comparison of the outputs of detectors 223 and 224.

This arrangement provides a simple and robust height and level detector that can be used as the confidence sensor in the second embodiment of the present invention as well as in other applications. The confidence sensor is primarily intended for initial set up and periodic, e.g. monthly, recalibration of the Z-interferometers of the measurement and exposure stations. However, the confidence sensor described above has a wider capture zone and more rapid response than the TIS used for precise determination of the position of the focal plane of the projection lens PL relative to substrate table WT. Accordingly, the confidence sensor 20a can advantageously be used, when the substrate table is first swapped to the exposure station, to make a coarse determination of the vertical position of the TIS. The height measured by the confidence sensor is related to previously measured best focus position(s) and used to predict a starting point and range for the TIS scan near the expected position of the best focal plane. This means that the TIS scan, described above, can be made shorter and hence quicker, improving throughput.

A beam splitter 215 that can be used in the confidence sensors is shown in Figure 18. A beam splitter is composed of a number of prisms from the same glass and preferably of equal thickness. The basic operation principle is described using a beam splitter consisting of 3 prisms 51, 52, 53. Prism 51 is trapezoidal in cross-section and the input beam 54 is incident normally on its top face 55 near one side. The position of input beam 54 is such that it meets one side face 56 of first prism 51 which is at 45° to the top face 55. Second prism 52 is joined onto side face 56 of first prism 51 and the join is coated so that a desired proportion of the input beam (half in the present embodiment) continues into second prism 52 to form beam 57 whilst the remainder is reflected horizontally within first prism 51 to form beam 58. Beam 58 reflected in first prism 51 meets the second side face 59 of that prism, which is parallel to the first side face 56 and is reflected downwards out of the lower face of first prism 51and through top and bottom faces of third prism 53 which are parallel to top face 55 of first prism 51. Second side face 59 may be coated as necessary to ensure total internal reflection of beam 58. Beam 57, which passed into second prism 52, is reflected internally by two parallel faces of second prism 52, which are perpendicular to side face 56 of first prism 51, and emerges from the bottom face of second prism 52 which is parallel to the top face 55 of first prism 51. Beams 57 and 58 are thereby output in parallel, but displaced. The separation between beams 57, 58 is determined by the sizes of prisms 51 and 52. Prism 53 is provided to equalize the optical path lengths of beams 57, 58 so that the imaging optics for both beams can be identical. Prism 53 also supports prism 52 as illustrated but this may not be necessary in some applications. To enhance the reflection of beam 57 at the surface where prisms 52 and 53 meet, a void may be left or a suitable coating provided.

Beam splitter 50 is simple, robust and easy to construct. It provides output beams in parallel (whereas a conventional cubic beam splitter provides perpendicular beams) and with equal path length. The splitting surface can be made polarization selective or not, and in the latter case can divide the input beam intensity evenly or unevenly as desired.

It is a feature of the level and confidence sensors described above, as well as other optical height sensors, that they are insensitive to tilt of the wafer stage about an axis perpendicular to the Z-direction defined by the intersection of the wafer surface WS

and the focus plane of the measurement spot of the level sensor 10. This is due to the fact that the sensors measure a height over the area of the measurement spot extrapolated to the spot's focus axis. The tilt insensitivity can be used to calibrate the Z-interferometers and the optical sensors towards each other in the XY plane. The procedure for such calibration is described with reference to Figure 19 and the level sensor, but a similar procedure can be used with the confidence sensor or any other similar optical sensor.

The positioning system of the substrate table is linked to the multi-axis interferometer system of which the Z-interferometer is a part, and can be set to apply a rotation about a selected axis in the XY plane using spaced-apart Z-actuators. To align the Z-interferometer measurement position with the level sensor measurement spot, the positioning system is used to rotate the stage about an axis passing through the Z-interferometer measurement position and parallel to, for example, the Y axis. The Z position of the table as measured by the Z-interferometer will remain unchanged during this tilt. If the level sensor and Z-interferometer are exactly aligned, then the wafer surface position will also remain unchanged. However, if the level sensor measurement position is offset from the Z-interferometer position by an amount δX, as shown in Figure 19, then tilting the substrate table WT to the position shown in phantom in that Figure will cause a change δW_{LS} in the level sensor output. The offset δX, and the offset δY in the Y direction, can therefore be quickly determined by detecting any change in level sensor output with tilts about two, preferably perpendicular, axes passing through the Z-interferometer position. The parameters of the interferometer system or the level sensor 10 can then be adjusted to ensure that the Z-interferometer measurement position is exactly opposite the level sensor measurement position.

Where the level sensor uses an array of measurement spots, it cannot always be ensured that the spots are exactly aligned. The above technique can therefore be used to determine any offsets of the individual spots from the nominal position w.r.t the Z-interferometer position. This information can then be used to correct the height map or the level sensor output.

Embodiment 3

The third embodiment employs the levelling principle of the first embodiment and is the same as that embodiment except as described below. The third embodiment may also make use of the hardware and refinements of the second embodiment, described above. However, the third embodiment makes use of an improved method for optimization of the exposure path. This is explained below with reference to Figure 20.

As discussed above, it is convenient and valid to consider that the substrate stage is stationary and that the exposure slit image moves, even though in practice it is the wafer that moves. The explanation below is given from this view point.

Figure 20 illustrates the notations used below. It should be noted that, although the slit image SI is depicted for clarity in Figure 20 spaced from the wafer surface, the aim of the optimization procedure is to ensure that during an exposure the focus plane of the slit image coincides as far as possible to the wafer surface. Considering a one dimensional wafer whose surface is defined by $w(y)$ and a slit image SI, the moving average (over time) defocus $MA(y)$ corresponding to a coordinate on the wafer can be calculated from:

$$MA(y)=\frac{1}{s}\int_{-s/2}^{s/2}\left[w(y)-[z(y+v)-v\,Rx(y+v)]\right]dv \qquad (2)$$

where the integral is taken over the slit size, s, in the scan direction and the integrand $w(y)-[z(y+v)-v.Rx(y+v)]$ is the focus error on a point of the wafer at a certain moment in time. Similarly, the moving standard deviation for a point on the wafer can be defined as:

$$MSD^2(y)=\frac{1}{s}\int_{-s/2}^{s/2}\left[w(y)-[z(y+v)-v\,Rx(y+v)]-MA(y)\right]^2 dv \qquad (3)$$

which is the defocus variation in time during the actual exposure of that point on the wafer. To minimize the difference between the plane of the exposure slit image and the wafer, a quadratic defocus term is used, defined as follows:

$$MF^2(y)=\frac{1}{s}\int_{-s/2}^{s/2}(w(y)-[z(y+v)-v\,Rx(y+v)])^2 dv \qquad (4)$$

where $MF(y)$ is called the moving focus. It will be seen that $MF(y)$ can also be written in terms of $MA(y)$ and $MSD(y)$ as follows:

$$MF^2(y) = MA^2(y) + MSD^2(y) \qquad (5)$$

This means that in the optimization of the exposure path and minimisation of the moving focus over the exposure area, both the moving average and the moving standard deviation are taken into account, in contrast to the simpler least-squares optimization of the first embodiment, which neglects any time, and thus scanning, integration. Equations [3] and [4] can easily be extended to two dimensions by adding $Ry(t)$ dependency and integrating MF over X from -W/2 to +W/2, where W is the width of the slit in the X-direction. To calculate the optimization it is convenient to use a frequency domain representation. Calculation in the frequency domain also enables high-frequency variations in the setpoints, that would result in excessive substrate stage accelerations in any or all of the degrees of freedom, to be filtered out, such that the exposure path is optimized for the performance of the substrate table positioning system.

In the above discussion, the optimum focus of the exposure slit image is assumed to conform to a plane; however, this is not necessarily the case: the optimum focus may in fact lie on an arbitrary surface, resulting in a so-called focal plane deviation (FPD). If the contour of that surface over the exposure slit area can be measured using the TIS to create a focus map f(x,y), or calculated, then the resulting data or equations can be added to the equations above so that the wafer motion is optimized for the actual optimum focal surface.

The optimization technique of the third embodiment can result in better focus for scanning systems and smoother substrate stage trajectories, increasing throughput and yield.

Embodiment 4

In a fourth embodiment, the level sensor is provided with additional features to counteract errors in the measurement of the wafer surface position that may be caused by interference between the beam reflected by the top surface of the resist layer and the beam refracted into the resist layer and reflected by its bottom surface. Otherwise, the fourth embodiment may be the same as any of the first to third embodiments described above.

The interference of beams reflected from said top and bottom surface is largely dependent on the resist properties and wafer surface properties, as well as on the optical wavelength and angle of incidence of the measurement beam. Broadband light sources and detectors are currently used to average out such single-wavelength interference effects. Improvement of this averaging principle can be realized if the wafer surface position is measured in a spectrally resolved manner, whereby a distinct measurement is performed for a number of wavelengths in the broadband measurement beam. To achieve this, it is necessary to make a temporally or spatially separated wavelength (color) system for measuring the wafer surface position. This necessitates changes such as the following to the level sensor's measurement principle.

A first possible change to the level sensor is to replace the continuous broadband light source by one capable of selectively generating light beams of different wavelength ranges (colors). This can, for example, be achieved by selectively interposing different color filters (e.g. on a carousel) at a suitable point in the level sensor's illumination system, by the use of several independently selectable light sources, by using a wavelength-tunable light source, or by using a selected beam portion from a rotating/vibrating prism located in a small broadband beam. The level sensor is then used to take several measurements of the wafer surface at each point, using different wavelengths of light in the measurement beam.

Another option is to replace the broadband detector by one capable of selectively detecting light of different wavelength ranges (colors). This can be achieved, for example, by placement of color filters in the detection optics before the detector, by spatially splitting the measurement beam for different wavelengths using a prism and then detecting the different-wavelength beams on separate detectors, or by any other

way of spectrally analyzing the broadband-reflected beam to measure the wafer surface position.

Naturally, it is also possible to use a combined approach, whereby both the projection system and the detection system are adapted to achieve spectral resolution.

In the absence of interference effects, each measurement (for each wavelength) should give the same result; consequently, if different results are obtained in such measurements, this indicates the presence of effects as referred to in the first paragraph above. An improved wafer surface position measurement can then be derived using a variety of techniques. For example, discrepant results may be corrected or discarded. Majority voting techniques may also be used. Alternatively, on the basis of a spectral measurement of the wafer surface position, one might even derive real positions by means of a model describing the spectral response of the resist and the wafer surface properties.

Since the described interference effect also depends on the angle of incidence of the measurement beam on the wafer surface, one might also want to vary this angle of incidence so as to evaluate the effect and then correct it. Accordingly, a further possible change to the level sensor is to adapt it such that the wafer surface position can be made using measurement beams at different angles of incidence. One way to achieve this is to define multiple measurement beams having different angles of incidence for the same spot on the wafer, but separate projection and detection optics systems. Alternatively, one can change the optical system so that the same projection and detection systems encompass the different optical axes pertaining to the various measurement beams. Another option, which generates temporally varying angles of incidence, is to use rotating/translating folding mirrors (or other movable components) in the optical systems of the level sensor.

As with the wavelength dependence described above, in the absence of interference effects, measurements at different angles of incidence should give the same result. Therefore, any discrepancies (variation with angle of incidence) can be avoided, compensated for, or modeled in the same way.

The above-mentioned additional features and improvements may, of course, be used together or separately, and in other optical sensors than those described here.

Embodiment 5

A fifth embodiment of the invention is shown in Figure 21. The fifth embodiment of the invention is a lithography apparatus employing, as the exposure radiation, extreme ultraviolet (EUV) radiation, e.g. of wavelength in the range of 9 to 16nm, and a reflective mask MA'. Functionally at least, the components of the fifth embodiment are generally the same as those of the first embodiment but they are adapted to the exposure radiation wavelength used and their arrangement is adjusted to accommodate the beam path necessitated by the use of a reflective mask. Particular adaptions that may be necessary include optimizing the illumination and projection optics IL', PL' to the wavelength of the exposure radiation; this will generally involve the use of reflective rather than refractive optical elements. An example of an illumination optical system IL' for use with EUV radiation is described in European Patent Application 00300784.6 (P-0129).

An important difference between lithography apparatus using reflective masks and those using transmissive masks, is that with the reflective mask, unflatness of the mask results in position errors on the wafer that are multiplied by the optical path length of the downstream optical system, i.e. the projection lens PL'. This is because height and/or tilt deviations of the mask locally change the effective angle of incidence of the illumination beam on the mask and hence change the XY position of the image features on the wafer.

According to the fifth embodiment of the invention, the effects of unflatness of the mask are avoided or alleviated by making a height map of the mask in advance of the exposure and controlling the mask position in at least one of Z, Rx and Ry during the exposure. The height map can be generated in a similar manner to that described above (i.e. off-axis levelling of the mask at a measurement station); however, it may also be generated with the mask at the exposure station, which may obviate the need to relate the height map to a physical reference surface. The calculation of the optimum position(s) of the mask during the exposure or exposure scan (the exposure path) can be equivalent to that described above, but it may also be a coupled optimization of wafer and mask exposure paths. However, for a mask, it may be advantageous to place greater weight in the optimization calculations on tilt deviations, since these will have a greater effect on the position at the wafer.

It should be explicitly noted that a lithographic projection apparatus according to the current invention may contain two (or more) substrate tables and/or two (or more) mask tables. In such a scenario, it is possible for a first substrate on a first substrate table to be undergoing height-mapping at the measurement station while a second substrate on a second substrate table is concurrently undergoing exposure at the exposure station; and similarly in the case of multiple mask tables. Such a construction can greatly increase throughput.

It should also be explicitly noted that the current invention can be applied to substrate leveling alone, to mask leveling alone, or to a combination of substrate leveling and mask leveling.

Whilst we have described above specific embodiments of the invention it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

4 Brief Description of Drawings

The present invention will be described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

Figure 1 depicts a lithographic projection apparatus according to a first embodiment of the invention;

Figure 2 is a view showing how the wafer height is determined from measurements by the level sensor and the Z-interferometer;

Figures 3 to 6 are views showing various steps of the off-axis levelling procedure according to the present invention;

Figure 7 is a plan view of a substrate table showing the sensors and fiducials used in the off-axis levelling procedure according to the present invention;

Figure 8 is a side view of the exposure and measurement stations in a second embodiment of the invention;

Figure 9 is a flow diagram illustrating various steps of the measurement process carried out at the measurement station of the second embodiment of the invention;

Figure 10 is a flow diagram illustrating various steps of the exposure process carried out at the exposure station of the second embodiment of the present invention;

Figure 11 is a diagram illustrating the scan pattern usable to measure the height map of the present invention;

Figure 12 is a diagram illustrating an alternative scan pattern usable to measure the height map of the present invention;

Figure 13 is a diagram illustrating the global level contour process in the second embodiment of the present invention;

Figure 14 and its sub-Figures A to G illustrate the structure and operation of a presently preferred embodiment of a level sensor usable in the invention;

Figure 15 is a graph showing detector output vs. substrate table position for a capture spot of the level sensor of Figure 14;

Figure 15A is a diagram showing the arrangements of detector segments for the capture spot of the level sensor of Figure 14;

Figures 16 and 17 are diagrams illustrating a presently preferred embodiment of a confidence sensor usable in the second embodiment of the invention;

Figure 18 is a diagram of a beam splitter usable in the confidence sensor of Figures 16 and 17;

Figure 19 is a diagram used to explain a Z-interferometer calibration procedure usable in embodiments of the invention;

Figure 20 is a diagram illustrating the notation used in describing an exposure trajectory optimization procedure according to a third embodiment of the invention; and

Figure 21 depicts a lithographic projection apparatus according to a fifth embodiment of the invention.

Fig. 1

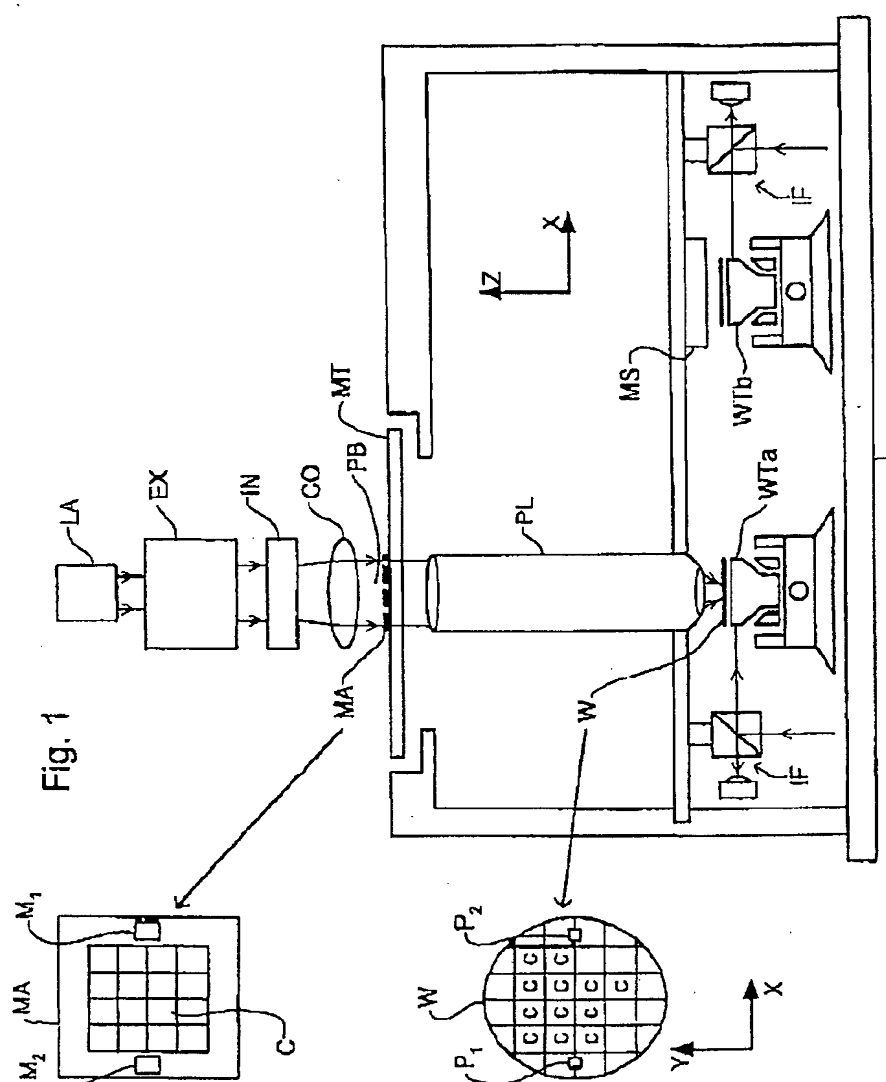


Fig. 2

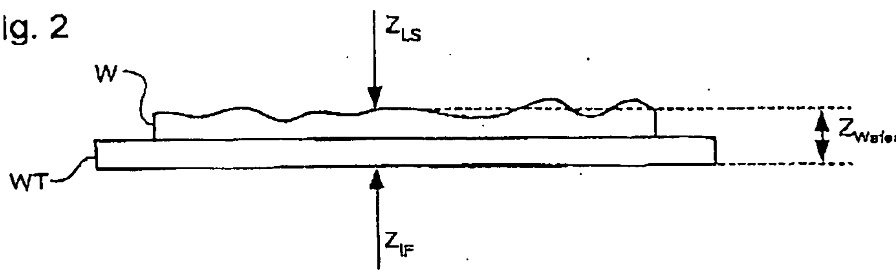


Fig. 3

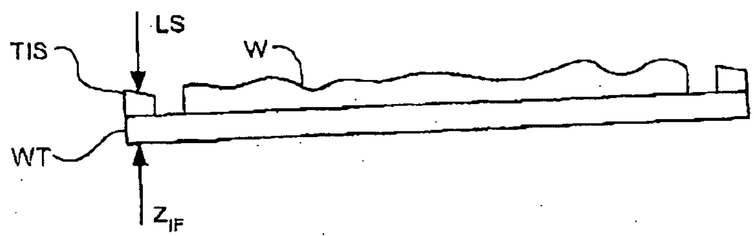


Fig. 4

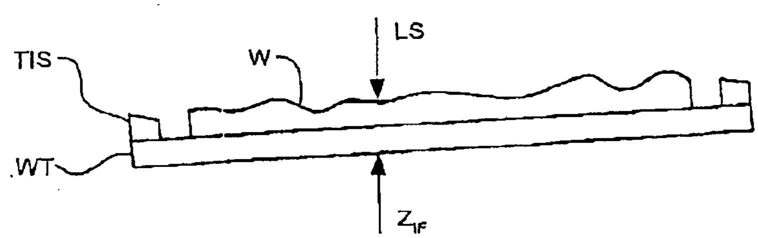


Fig. 5

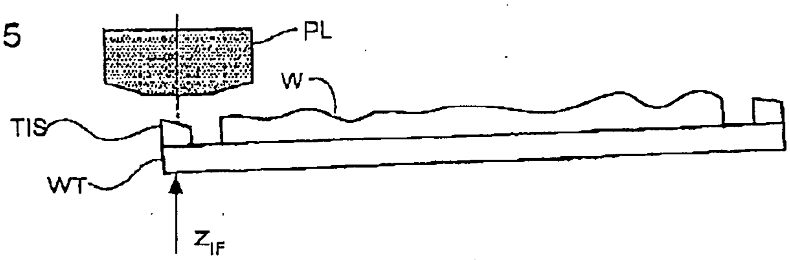


Fig. 6

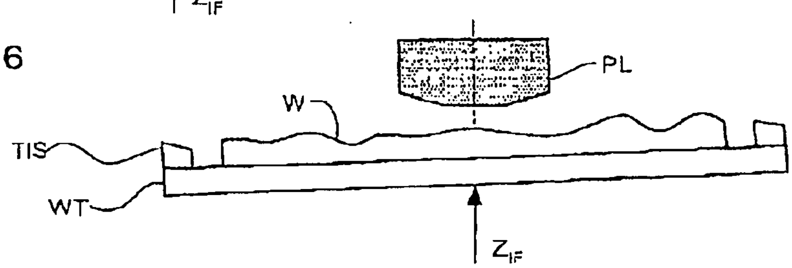


Fig. 7

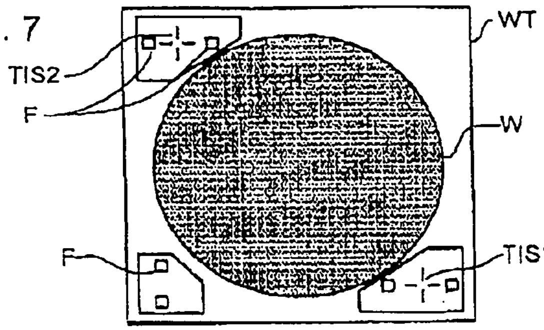


Fig. 9

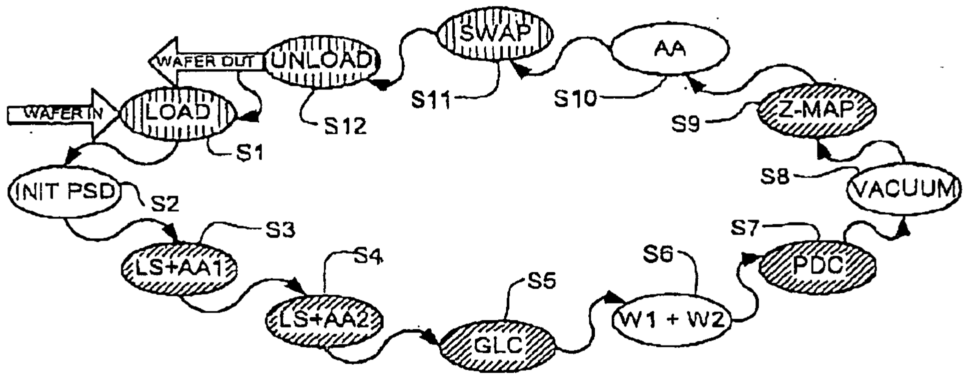


FIG. 10

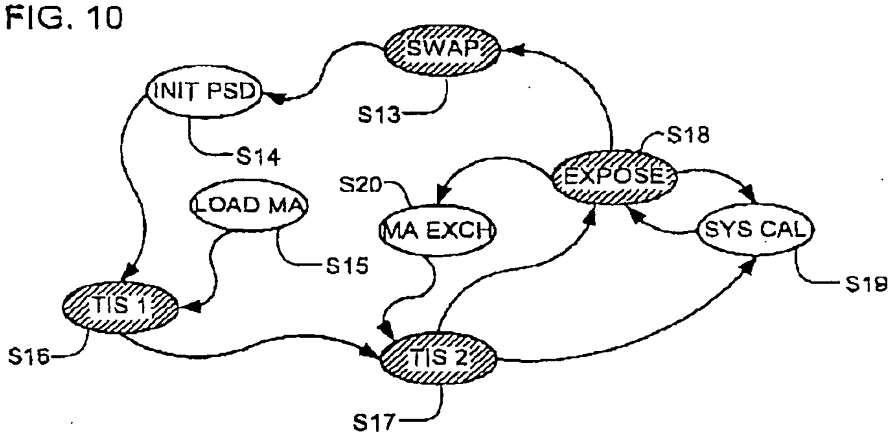
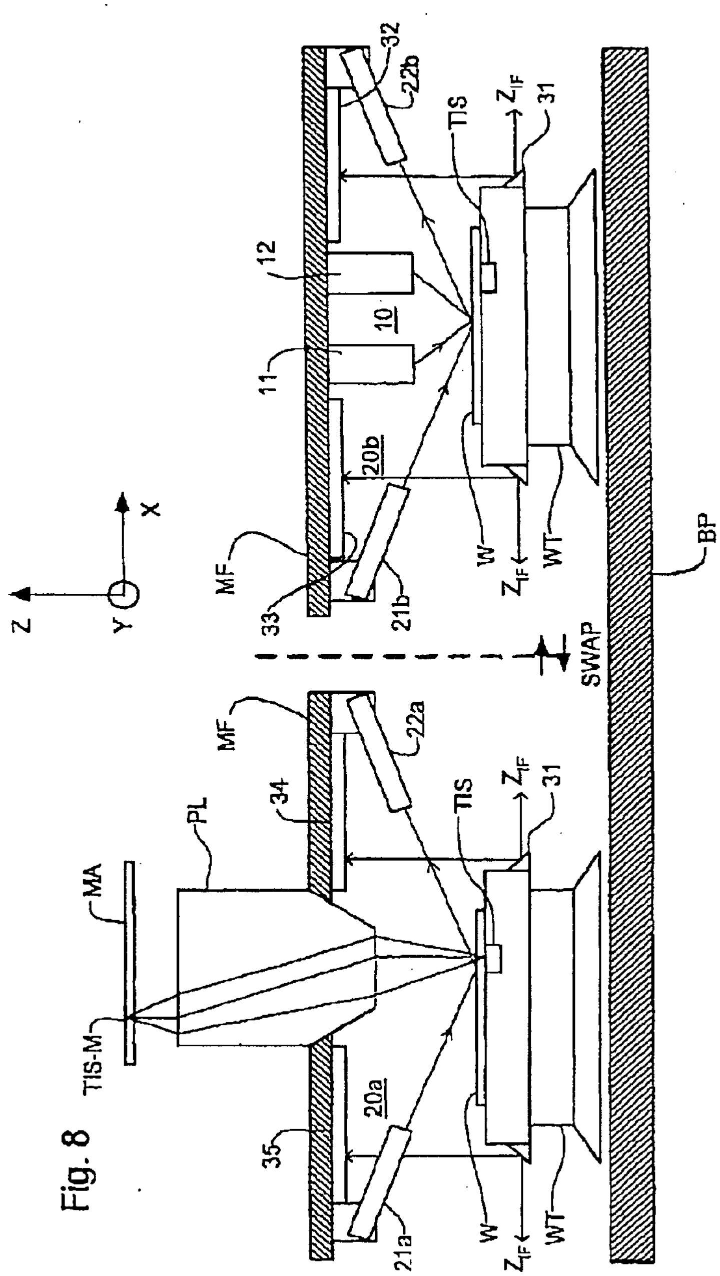


Fig. 8



Z
X
Y
MF
33
21b
20b
11
10
12
TIS
Z_{IF}
31
22b
32
W
WT
BP
SWAP
MA
PL
TIS-M
35
20a
21a
34
22a

Fig. 11

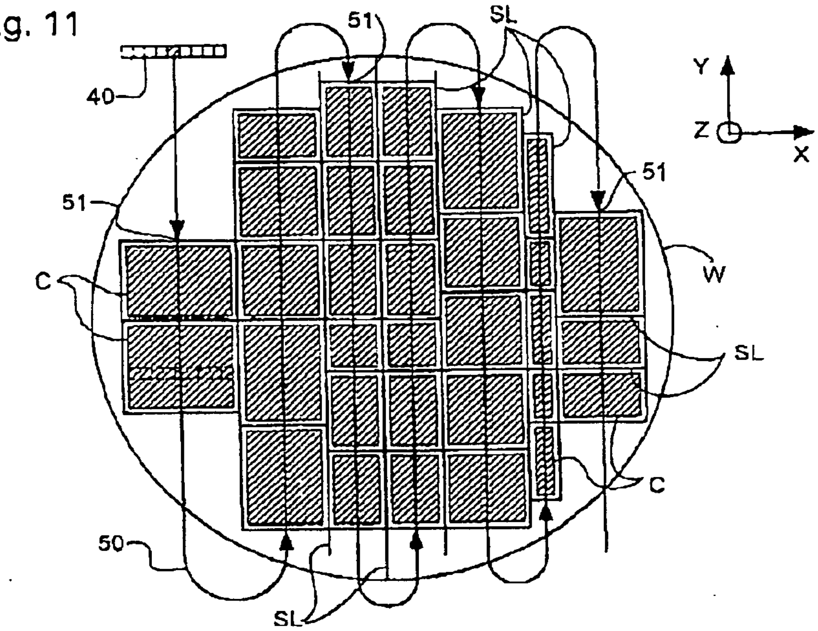


Fig. 12

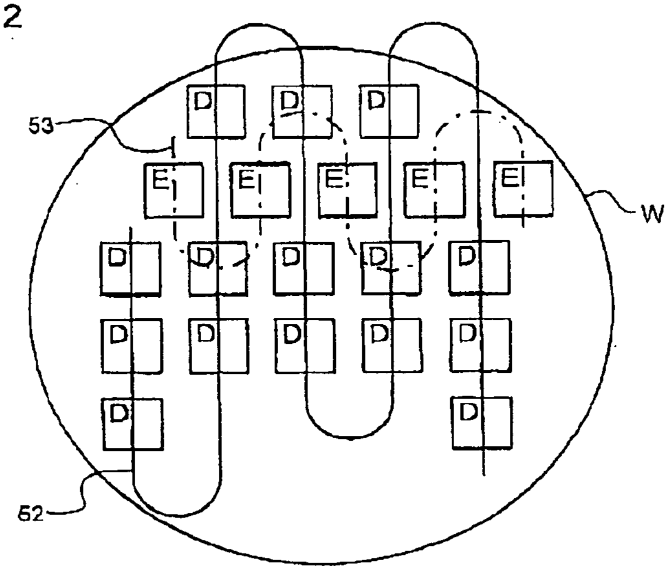


Fig. 13

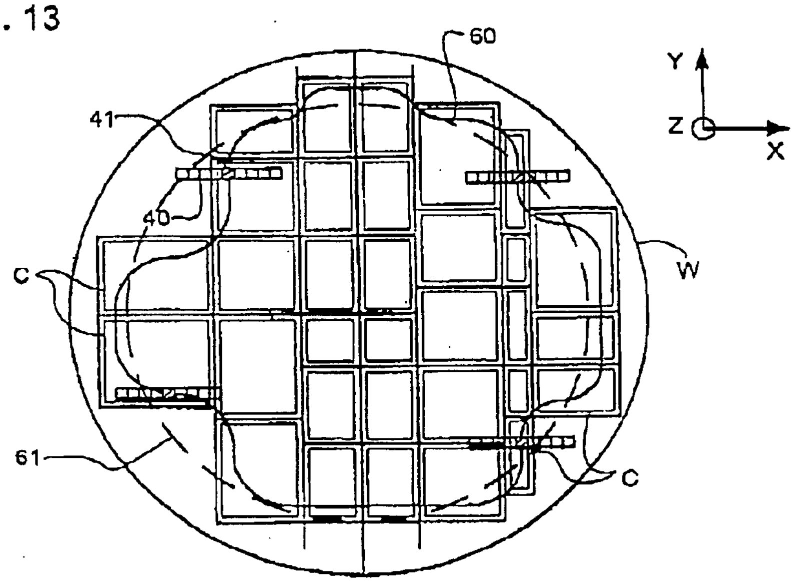


Fig. 15

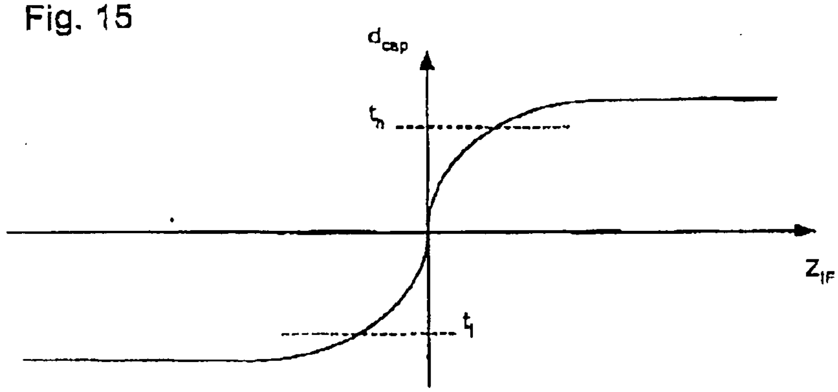


Fig. 15A

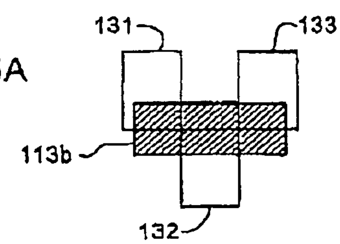


Fig. 14

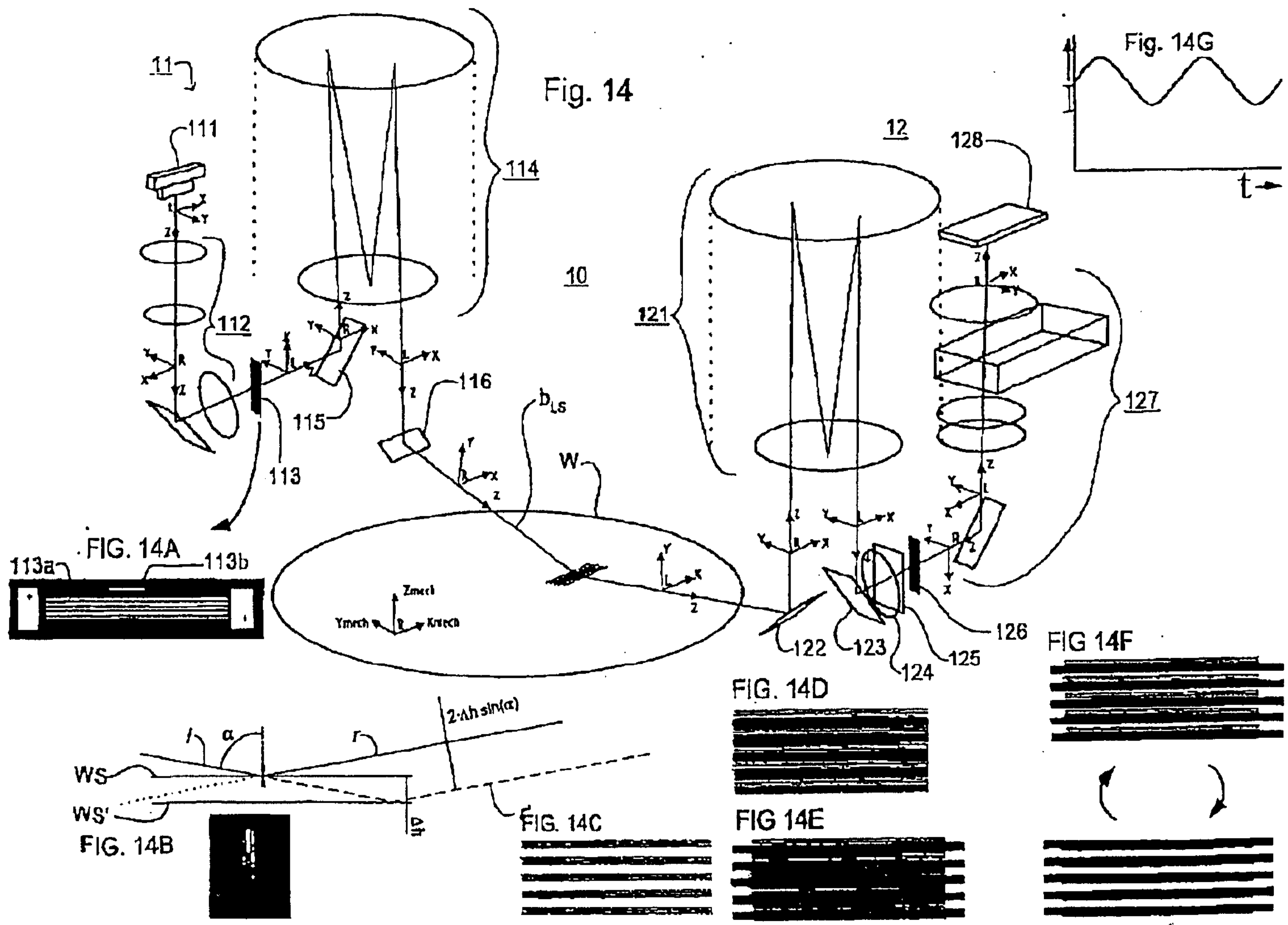

11
111
112
113
114
115
116
10
12
121
122
123
124
125
126
127
128
W
b_{LS}
Zmech
Ymech
Xmech
FIG. 14A
113a
113b
WS
WS'
FIG. 14B
α
2·Δh sin(α)
Δh
FIG. 14C
FIG. 14D
FIG 14E
FIG 14F
Fig. 14G
t

Fig. 16

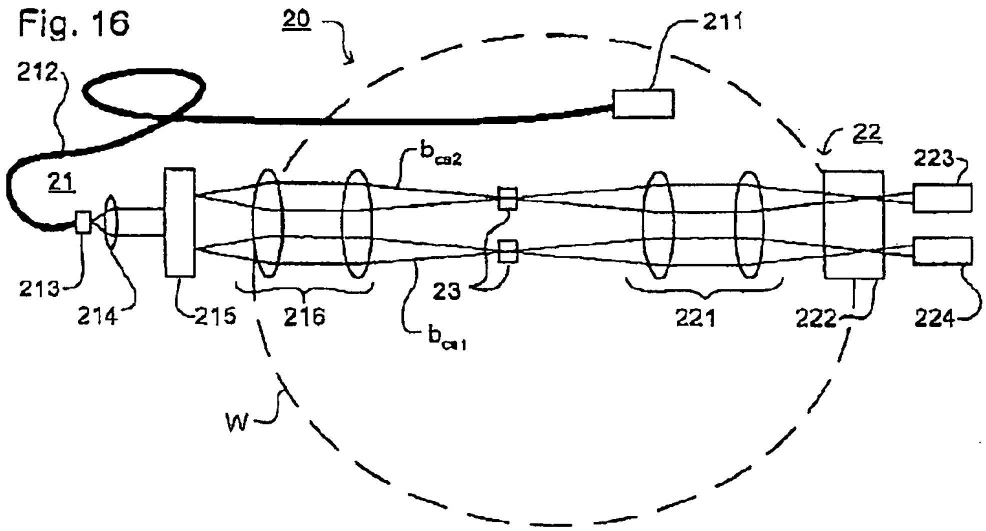


Fig. 17

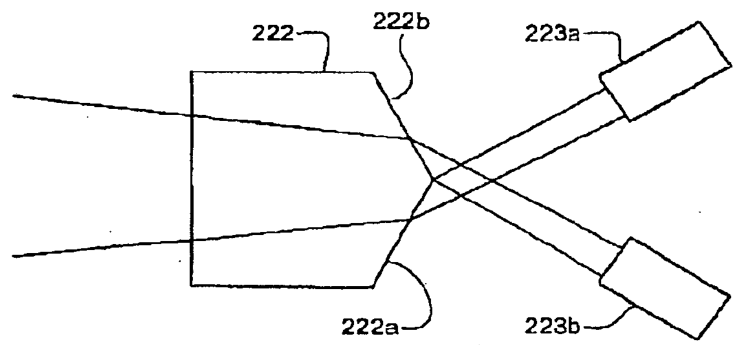


Fig. 18

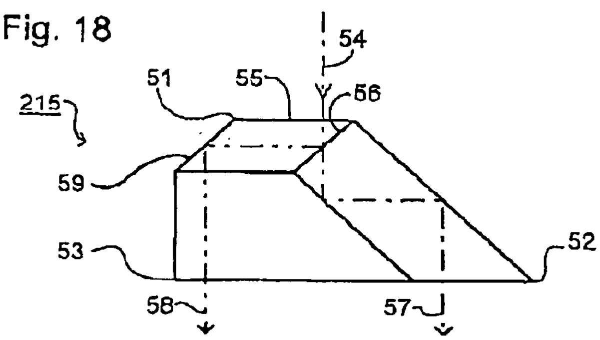


Fig. 19

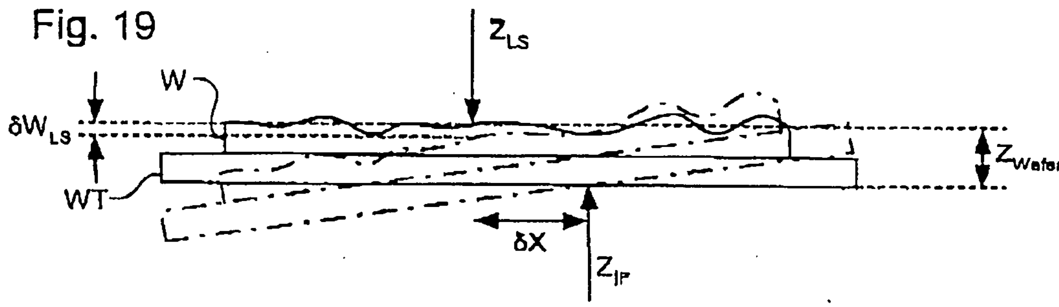


Fig. 20

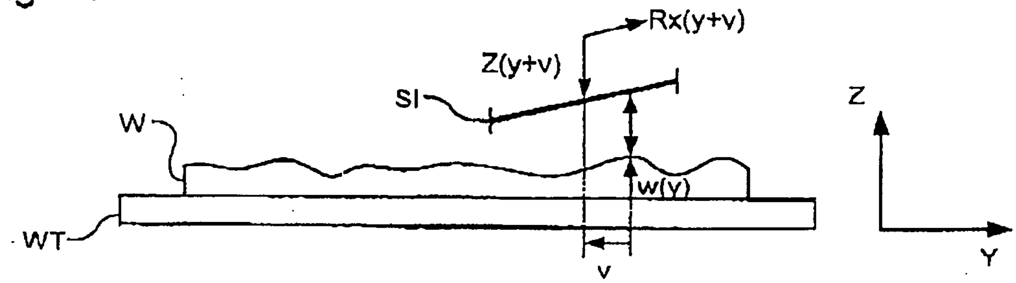
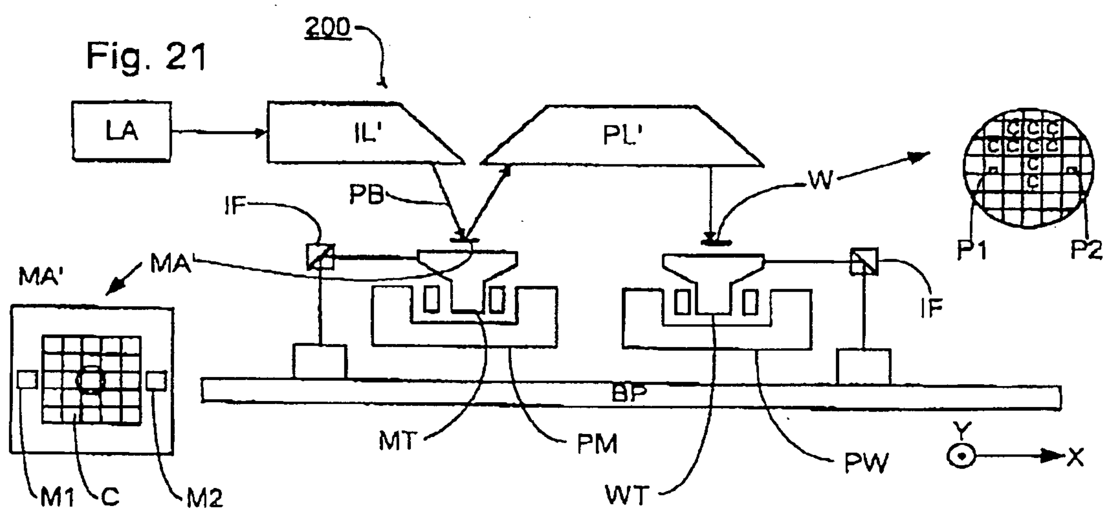


Fig. 21



1 Abstract

In an off-axis levelling procedure a height map of the substrate is generated at a measurement station. The height map is referenced to a physical reference surface of the substrate table. The physical reference surface may be a surface in which is inset a transmission image sensor. At the exposure station the height of the physical reference surface is measured and related to the focal plane of the projection lens. The height map can then be used to determine the optimum height and/or tilt of substrate table to position the exposure area on the substrate in best focus during exposure. The same principles can be applied to (reflective) masks.

2 Representative Drawing

Fig. 8